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MSC THESIS

ENVIRONMENTAL GUIDE FOR ASW IN EASTERN CANADIAN SHALLOW WATERS

Part I - An Assessment of the State of Knowledge

BY

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Environmental Guide for ASW in Eastern Canadian Shallow Waters

Part I - An Assessment of the State of Knowledge

By

Capt Daniel Normand

Authors Note

This thesis consists of the following three parts:

Part I - An Assessment of the State of Knowledge
Part II - Environmental Data
Part III - Classified Data

A Table of Contents for all three parts is included at the end of each volume.

ENVIRONMENTAL GUIDE FOR ASW IN EASTERN
CANADIAN SHALLOW WATERS

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Abstract

This guide identifies and presents information on environmental parameters that can affect ASW operations in the shallow water areas off the east coast of Canada. The first part of the guide is an assessment of the state of knowledge on each of the parameters covered. The impact of the parameters on ASW operations is assessed and the resolution and coverage required for each parameter is defined. Existing data sets are then examined, evaluated and deficiencies noted. Areas where future efforts in data collection should be placed can thus be identified. The second part contains the actual environmental information for a broad range of parameters covering the following categories: bottom features, climatology, oceanography, biological activity, economic activity and acoustics. The information is presented in a summary format such that areal distributions and temporal variability can be readily accessed by non-specialist users. All parts of this guide should provide the user with a better knowledge of the environmental particulars of the area and permit a better use of ASW assets.

Finally, the potential of Geographic Information Systems (GISs) for the storage, retrieval and display of this environmental data is investigated. A simple PC based GIS application was developed and is presented.

Aknowledgements

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The author is grateful to the Director Maritime Operational Research for funding which enabled the project to be completed and expanded to include the GIS. I thank the Bedford Institute of Oceanography and the Defence Research Establishment Atlantic for the data provided. I am particularly grateful to Kevin Robinson (BIO), Steve Hughes (DREA) and Mat Pindam (MARCOM) for their assistance in getting the various data sets I needed. Finally, a thank you to LCdr. Mark Tunnicliffe for his suggestions that helped to start the project on the right note.

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Chapter 1

Introduction

This environmental guide identifies and presents information on oceanic parameters which affect ASW systems. The information must be as complete as possible in order to be useful for planning purposes, yet it cannot, without becoming cumbersome to use, contain all the detailed data necessary for acoustic performance prediction in a specific situation. Thus, information is presented in a summary format such that their areal distribution and temporal variability can be readily accessed and extracted by non-specialist planners. The present guide limits itself to the continental shelf area off the east coast of Canada from the CANLANT western boundary (66°W) to the Strait of Belle Isle, including the Gulf of St. Lawrence.

Two basic groups of information are presented. The first group consists of general environmental aspects which provide a climatological and oceanographic perspective of the area of interest. These provide users who are not already familiar with the area with a good description of the basic features. The second group consists of specific ASW considerations and includes data of a more direct application to ASW operations. All portions of this guide taken

together should help mission planners to take better advantage of the specific conditions found in the area of interest, and to adjust tactics accordingly.

The information presented in this guide has been obtained from various civilian, government, and military organizations. Some could be readily used, others had to be adapted into a more usable format. The guide also identifies areas where the data are incomplete or non-existent; it therefore identifies where future data acquisition programs should concentrate to aid ASW.

The environmental parameters considered cover the following categories:

- Bottom features
- Climatology
- Oceanography
- Biological activity
- Economic activity
- Acoustics

The information on these parameters has been regrouped into two parts:

- **Part I:** - contains an assessment of the state of knowledge on each of the parameters covered. It should be consulted whenever a question arises regarding the source or exact nature of the data. The information is generally organized as follows:
  - description of the parameter
  - its impact on ASW
  - its variability (spatial and/or temporal)

- the resolution required for ASW
- existing data set:
  * sources of data (agencies, data sets)
  * technique or methodology used to collect the data
  * resolution and accuracy of the data
  * coverage provided.

- **Part II:** - contains the actual environmental information for each of the parameters. The information is presented as follows:
  - description by region
  - significant anomalies and special features
  - data products (presentation)

The last element of this project consists of an investigation of the potential of Geographic Information Systems (GISs) for the storage, retrieval and display of the information presented in this study. GIS are characterized by their ability to link map elements to databases which contain descriptive attributes and to perform "spatial analysis" ie., the exploration of the relationships between these attributes. These systems are becoming increasingly popular in the oceanographic and satellite remote-sensing communities, and other scientific fields where the demand for spatially oriented databases is important. A simple PC based GIS application was developed and is presented.

Chapter 2

Bottom Features

Bottom characteristics such as bathymetry and surficial geology, are critical parameters when dealing with the problem of shallow water ASW, due to the increased importance of bottom interaction with sound propagation. A good knowledge of these bottom parameters is an essential prerequisite when attempting to predict the performance of ASW sensors or weapon systems.

Since a greater portion of the acoustic energy interacts with the bottom than in deep waters, it is generally accepted that the acoustic properties of the seafloor (geoacoustics) must be included in any model used to predict sound propagation in shallow water. Such a model, to be complete thus requires: water mass data, detailed bathymetry, profiles of the sea subfloor, as well as true thicknesses and properties of the sediment and rock layers in the sea floor. A description of the first few metres may be sufficient for higher frequencies, whereas lower frequencies usually require a description of the entire sediment column [Hamilton, 1980]. At very low frequencies (<20 Hz), the seabed and sub-bottom must be considered an integral part of the propagation medium. At these frequencies, not only compressional waves, but other propagation

mechanisms such as shear waves and interface waves in the sediment can play a significant role in the sound propagation.

2.1 Bathymetry

The water depth is obviously one of the critical parameters that must be considered by a submarine operating in shallow water. For units engaged in ASW, the bathymetry is also very important since it affects the performance of many sensors and weapons systems.

2.1.1 Impact on ASW

The bathymetry impacts on ASW operations in several ways. In shallow areas, submarine manoeuvres are restricted and hence, large nuclear submarines tend to avoid these areas altogether. Bottom features such as canyons, can be used effectively for tactical purposes. The use of systems such as a towed array or a variable depth sonar (VDS) is impeded, and the guidance system of some weapons designed mostly for open ocean use, do not perform well in the presence of strong bottom reflections. Non-acoustic systems, such as magnetic anomaly detectors (MAD) are also affected. MAD performance is degraded due to the increased noise level in areas of sharp relief features [B. Nelson, DREP, informal communication].

Acoustic sensors are affected in several ways. The proximity of the bottom to the surface results in a channel that acts as a bandpass filter for low frequencies. This low frequency cut-off corresponds to the frequency of the first mode in normal mode theory. The wavelength of this first mode is given by

$$\lambda_c = 4H$$

where λ_c is the cut-off wavelength and H is the water depth [Urick, 1982]. When the bottom is not completely "hard", the relation becomes

$$\lambda_c = \left(\frac{4H}{[1-(c_1/c_2)^2]^{1/2}}\right)$$

where c_1/c_2 is the velocity ratio in the water to that in the bottom [Urick, 1982]

Note that at very low frequencies (VLF)(below 10 Hz), particularly below the cut-off frequency, the acoustic energy may still propagate as interface waves or Scholte waves as seen in Figure 2.1. Interface waves are a combination of compressional and shear waves travelling on the interface between a solid and a liquid. These waves are characterized by amplitudes that decay exponentially away from the interface. At VLF, both waterborne sources and wind-wave action at the surface can lead to the excitation of Scholte waves and hence to the propagation of acoustic energy, including ambient noise, in the sea bed and in the water column, even at frequencies below the acoustic waveguide cut-off [Ali, 1990].

Urick [1982] also found that better transmission occurs in the direction of constant water depth than either upslope or downslope. In addition to the waveguide cut-off problem, the upslope poor transmission is also the result of an increasing number of bottom encounters, while in the downslope direction, the poor transmission is likely due to the effect of downward refraction which carries sound energy away from the near-surface receivers.

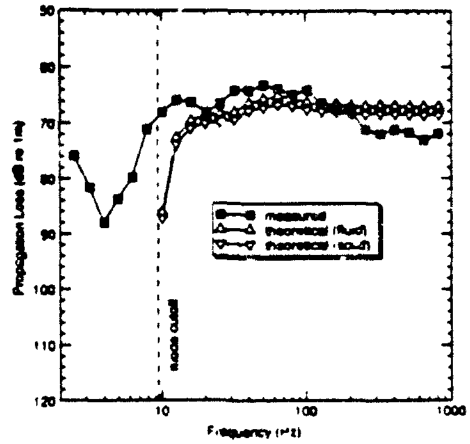

Figure 2.1: Measured propagation loss versus frequency over a thick bank of sand (filled square), and theoretical propagation !oss using two different models. Increased energy below 4 Hz is probably associated with interface waves. (From Hughes et al., 1990)

At frequencies above a few kilohertz, the bottom relief as represented by its roughness, plays a major role in the amount of reflection. Reflection from very rough bottoms tends to be less than from smooth bottoms [Brekhovskikh and Lysanov, 1982].

2.1.2 Variabili:y

The eastern continent shelf is a large area that can be divided into subareas with very dissimilar topographic features, ranging from the smooth expanses of the Grand Banks (depth $\sim$ 60 m) to the rugged topography of the Northeast Scotian Shelf area, or the steep slopes and deep section of the Laurentian Channel (depth $\sim$ 600 m).

2.1.3 Resolution Required

The resolution of the bathymetric data required for ASW operations must display any topographic features that could be tactically exploited by a submarine. It must also provide adequate input for acoustic prediction models. A depth resolution of 10 m is deemed sufficient for a planning document.

2.1.4 Data Set

Data source

Bathymetry for this guide is taken from the following charts of the Canadian Hydrographic Service (CHS) of the Department of Fisheries and Oceans:

- Map 801-A Bay of Fundy to Gulf of St. Lawrence (Bathymetry);
- Map 802-A Newfoundland Shelf (Bathymetry);
- Map NM 19B Chicoutimi (Lower St. Lawrence Estuary);
- Map NM 21B Strait of Belle-Isle.

These 1:1,000,000 charts provide bathymetric information with a depth resolution of 10 m.

Most of the area has been surveyed within the past thirty years [CHS, Status of Surveys Chart, 1989] using electronic echo sounders. The sounding lines were run, as nearly as possible, at right angle to the bathymetric contours. A systematic pattern of check lines, was also run at right angles to the principal sounding lines over the entire survey area. Cross-depth discrepancies between check lines and regular sounding lines are not greater than 0.5 m in depths up to 30 m and not greater than 1.6% of the depth in depths over 30 m [CHS, 1990].

Line spacing varies from 50 m in harbours and channels, to several kilometres in offshore locations. Since the bottom is relatively smooth where large spacing is used, it is unlikely that any feature of a scale that could affect ASW operations has been missed.

Data quality

The major sources of error associated with bathymetric surveys are:

- uncertainty in the chart datum and the tidal data used to reduce the sounding to chart datum (vertical control),
- uncertainty in vessel position (horizontal control),
- inaccuracy in the echo sounder and sounding trace,
- inaccuracy in sound speed.

The first two are the most important. The quantity and quality of bathymetric data vary mostly as a function of the distance to shore. In general, surveys near the shore are done according to a tighter grid and the position accuracy is better. The data are collected to meet the requirements to produce large scale charts (1:50,000 or larger). The accuracy or amount of details presented must be reduced by ten fold to be included on the smaller scale charts (1:1,000,000) used in this guide, [Warden, 1991, personal communication].

Data collected farther offshore are subject to errors associated with larger grid spacing and lesser position accuracy, particularly for the data collected before the advent of modern navigation systems such as LORAN-C and the Global Positioning System (GPS).

Digital data sources

- CHS is in the process of converting its database into digital format (CARIS). Digital bathymetric data should therefore be available from CHS in the near future.

- The National Geophysical Data Centre (NGDC) has produced ETOPO5, DBDB5 and DBDBC (Classified) [NGDC, 1985 and 1886]. These are global topographic databases which contain 12 data points per degree of latitude and longitude.

- Oceanroutes Canada Inc. [Traves and Deveau, 1989] has developed an acoustic prediction database for the Defense Research Establishment Atlantic (DREA) based on ETOPO5 for the present area of interest.

2.2 Sediment Types

With the exception of a few small rock outcrops, the continental shelf bottom is covered by one or several layers of unconsolidated sediment which form a generally thin blanket over the bedrock. These sediments can have a very strong impact on the propagation of sound in shallow water.

2.2.1 Impact on ASW

As mentioned before, at frequencies above a few kilohertz, the bottom relief plays a dominant role in the sound interaction with the bottom. At lower frequencies however, the sediment parameters are the determinant factors which control the sound reflection, refraction and attenuation [Brekhovskikh and

Lysanov, 1982].

Reflectivity. The physical properties of density and sound velocity in the sediment determine bottom reflectivity. These properties define the characteristic impedance of the sediment, and the impedance mismatch between the two layers (seawater and sediments) determines the amount of energy which is reflected when sound passes from one medium to the other. These properties vary for different sediment types, and as a result, different bottom bounce behaviour resulting from the reflection, refraction or absorption due to the sediment, can be expected in areas with different bottom type.

Attenuation. According to Hamilton [1980], the attenuation (dB m^{-1}) of compressional waves in most saturated sediments is proportional to the frequency (from < 10 Hz to at least 1 MHz). There is also a dependence on sediment type with the proportionality constant for the attenuation about an order of magnitude greater for sand (large grain size) than for silty clay (small grain size), for frequencies between 10 kHz and 1 MHz. Attenuation reaches a peak at porosity of 50% to 55% (usually found in very fine to silty sand) and drops to low values for porosity above 70% (clayey silt, clay). Expressed in terms of grain size, attenuation reaches a maximum for sediments in the range of 0.03 to 0.10 mm. The dependence of attenuation on depth is not well known. It appears that for small grain sediment like silty clay, attenuation initially increases with depth for the first few hundred metres before decreasing asymptotically to low values, whereas in sand, the attenuation is highest at the seafloor and then decreases most rapidly in the first hundred metres of

sediment. Attenuation of shear waves is less understood, but there seems to be a dependence on the first power of the frequency [Hamilton, 1980].

Scattering. Sediment type can give an indication of the backscattering properties of the bottom. For sound whose acoustic wavelength is of the same order as the sediment size, scattering should significantly degrade sonar performance. In the case of ASW sonars using frequencies between 1 to 10 kHz, sediments such as Scotian Shelf drift which contains boulder size fragments could be an important cause of sound scattering. It appears however that the roughness of the sea bottom is the dominant characteristic for backscattering [Urick, 1983]. The bottom roughness associated with a given sediment type is therefore a better indication of the backscattering strength.

2.2.2 Variability

The variability of the sediments is high over most of the area; it is related to the rugged topography, the various geomorphologic mechanisms that were involved since the last glacial age in the deposition of these materials, and the action of currents which causes a further winnowing of the deposits.

2.2.3 Resolution Required

The sediment type is a basic input of a geoacoustic model. Ideally, the following information on each sediment and rock layer should be available [Hamilton, 1980]:

- Sediment and rock types at the seafloor and underlying layers,
- True thickness and shape of layers, as well as the location of significant reflectors,

- Compressional wave (sound) velocity,
- Shear wave velocity,
- Attenuation of sound ,
- Attenuation of shear wave,
- Density.

If that information were available, it would constitute a huge amount of data more suited for inclusion in a tactical computerized database than in the present guide. This guide therefore identifies only the uppermost sediments.

The spatial resolution in a planning document should permit the identification of regions with relatively homogeneous sediments of 500 km^2 or more. In areas where the variability of the sediment type is very high, the sediments should be regrouped into a different category expressing that variability in order to avoid chart clutter.

2.2.4 Data Set

Data source

The information on sediment types is contained in a series of surficial geology charts produced jointly by the Geological Survey of Canada and the Canadian Hydrographic Service. These 1:300,000 charts provide a detailed representation of the surficial geology for most of the area of interest.

The maps are the following:

- Map 4040G - Halifax-Sable Island (Surficial Geology);
- Map 4039G - Yarmouth-Browns Bank (Surficial Geology);

- Map 4041G - Banquereau and Misaine Bank (Surficial Geology);
- Map 4011G - Eastern Gulf of Maine and Bay of Fundy (Surficial Geology);
- Map 4013G - Canso Bank and Adjacent Areas (Surficial Geology);
- Map 4015G - Laurentian Channel and the Western Grand Banks of Newfoundland (Surficial Geology);

Methodology used

Echograms collected during geological and bathymetric surveys are used to determine the type of sediments present. They enable the tracing of formations, the recognition of the stratigraphic relations of these surficial formations and the measurement of the thickness of the layer where the sound energy is able to penetrate the sediment. The acoustic information from the echosounder (14.25 kHz) is then verified using bottom sampling. This method provides much better coverage than would be obtained though sampling only, and yields a map with a high degree of detail [King, 1970]. The continuous acoustical profile along the survey path yields more complete information than discrete sampling stations only.

Data quality

The accuracy of the map is a function of the spacing between tracks and the quality of the interpretation of the echosounder profiles. The frequency of bottom sampling stations was judged by the teams involved in the profile interpretation to be adequate to ensure a good control. Track spacing varies

greatly between areas. Near the coast of Nova Scotia to 60°W (inner and central shelf), the survey tracks were generally spaced at one half mile intervals along a north-south axis or along an axis perpendicular to the major morphological trend [King, 1970; Drapeau and King, 1972]. Elsewhere, the survey tracks were usually spaced at two mile intervals, with the exception of some parts of Banquereau Bank and other selected patches, where the spacing was one mile [MacLean and King, 1971]. Over the southern part of the Laurentian Channel and most of St. Pierre Bank a ten mile grid was used and for the northeast portion of the Scotian Shelf and the Browns Bank area a five mile grid was used [Fader et al., 1982].

The accuracy of the results is judged acceptable for the present needs. A track spacing of one half mile to two miles is likely to reveal any significant features at the scale of interest. Larger spacing was used when the knowledge obtained from surveys in adjacent areas of similar geomorphology indicated that a reduction in sampling density would be appropriate.

Data coverage

The Gulf of St. Lawrence, the Scotian Shelf, and the western part of the Grand Banks are covered. Data are missing for the remainder of the Grand Banks and the east coast of Newfoundland with the exception of the Hibernia area where oil exploration is taking place (Fig 2.2).

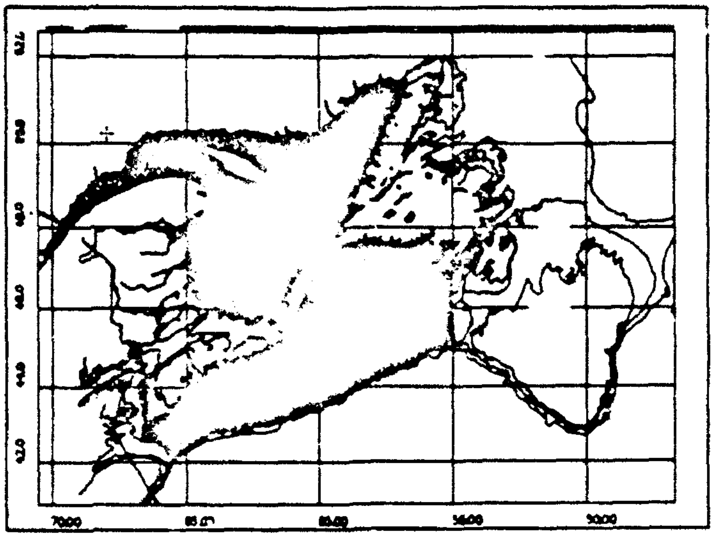

Figure 2.2. Area covered by surficial geology surveys.

2.3 Sediment Thickness

The sediment thickness considered is that of the unconsolidated sediments only. The reported thickness usually includes several layers of distinct sediments which are often difficult to differentiate.

2.3.1 Impact on ASW

The sediment thickness is an important parameter for low frequency propagation in the deep ocean. For these frequencies, the sound speed profile within the sediment layer may be considered to be an extension of the speed profile in the water mass. The sound speed increases with depth of sediment. This increase in speed, combined with sufficient sediment thickness, can provide a bottom refraction path which returns energy transmitted into the bottom back into the water column. In the deep ocean, where sediment thickness often

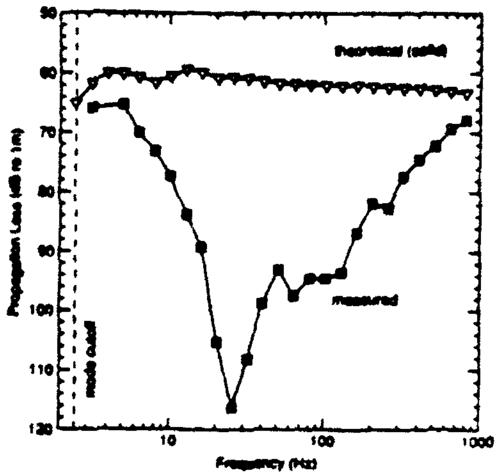

Figure 2.3: Sound attenuation over a thin layer of sediment overlying hard rock shown by the high propagation loss measured at 25 Hz. The theoretical data show that average models cannot account for this loss. (From Hughes et al., 1990)

exceeds 200 m, convergence mode propagation through the sediment layer is even possible. In the area under investigation however, the thickness of the sediments seldom exceeds 90 m and is usually in the order of 30 m. Therefore convergence zone propagation into the sediments is not possible.

Large patches with only a few metres of sediments are also common. Hughes et al. [1990] have measured very high propagation loss over a wide band of low frequencies (10 to 100 Hz) in shallow water areas with partially exposed hard rock seabeds, or hard rock seabed covered only with a thin layer of sediment, as shown on Figure 2.3.

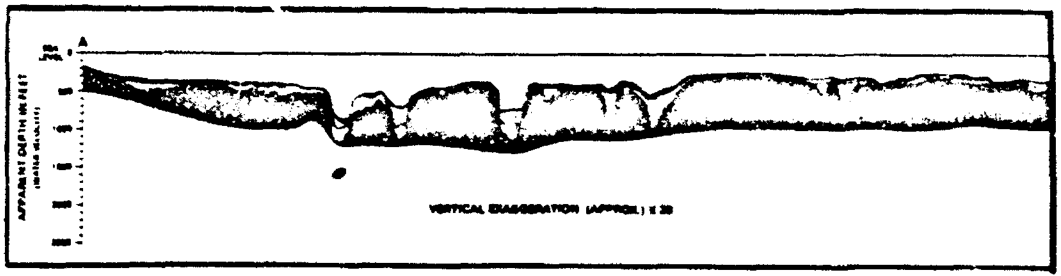

Figure 2.4: Sediment thickness distribution over a rough underlying bedrock-Misaine Bank area. (From CHS Chart No. 4041G)

2.3.2 Variability

The variability of sediment thickness is high due to the numerous geomorphological processes that have contributed to the formation of the layers, combined with the high topographic variability. As a result, the variability tends to be higher where the topography is rugged and lower where the bottom is flat. It is particularly high in areas such as the northeast portion of the Scotian Shelf where the underlying bedrock surface is very irregular (Fig 2.4).

2.3.3 Resolution Required

In order to be able to correctly predict propagation paths of low frequency sound, we would require not only the knowledge of the sediment thickness at all locations, but also the knowledge of the different sediment layers present,

their respective thicknesses, the shape of the layers, as well as the location of significant reflectors (which may vary with sound frequency). This type of data is not available at the present time. At best, we have some estimates of the total depth of the unconsolidated sediments.

2.3.4 Data Set

The source document for sediment thickness on the eastern Canadian continental shelf is a report produced by King et al. [1985].

Procedure used

The thickness data were obtained from seismic reflection data analysis. This analysis was supplemented, in the case of the Scotian Shelf by a qualitative assessment derived from information on the surficial geology maps listed in Section 2.2.4. An affinity between the sediment thickness and the sediment type indicated on these maps allows this type of assessment [King et al., 1985]. Over most of the area, the amount of data is limited, track spacing is wide and the grid is irregular. The highest resolution was obtained using a grid spacing of 30 km.

Data coverage

Data on sediment thickness are available for the Scotian Shelf and the Grand Banks (Fig. 2.5). There are no data for the Gulf of St. Lawrence. Contour drawing was not possible over most of the Grand Banks due to the lack of surficial geology compilation that would have supported a qualitative

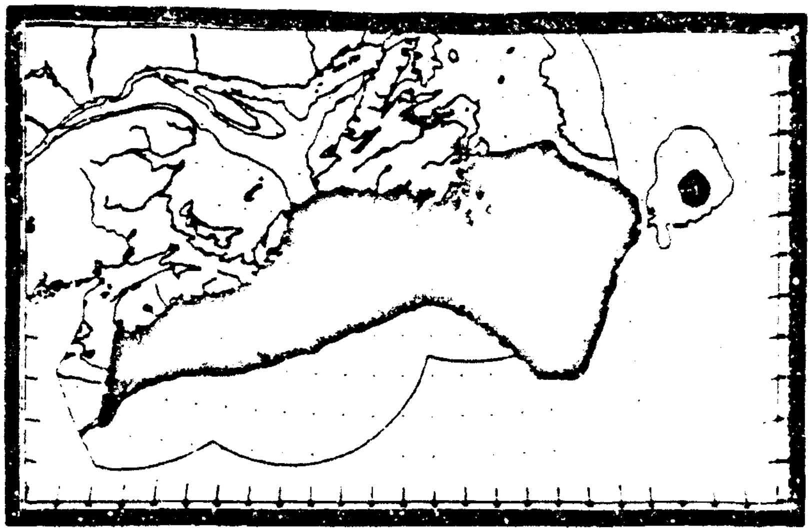

Figure 2.5: Sediment thickness survey coverage.

assessment of the sediment thickness based on the sediment type (as done for the Scotian Shelf area), and due to the extent of thin to highly variable sediment cover (as opposed to continuous large thickness). For the most part, only qualitative designation of sediment thickness was given for this area [King et al., 1985].

Digital data

A digital database was developed under a DREA contract by Oceanroutes Canada Inc. [Traves and Deveau, 1989] based on the study by King et al. [1985].

2.4 Physiographic Provinces

Physiographic provinces represent areas of similar topographic, structural and morphological characteristics that are likely to show a similar acoustic response.

2.4.1 Impact on ASW

Given the properties of sound propagation in shallow water, these provinces relate to areas of different acoustic response to sound interacting with the ocean bottom. The rate of transition between different physiographic zones must also be considered; for instance, where province boundaries reflect abrupt changes from high to low relief, changes in acoustic response will also be abrupt.

2.4.2 Variability

Since these provinces are determined from two other highly variable parameters (topography and surficial geology), the variability found in the acoustic response within some of these provinces is very high. Areas like the Grand Bank and the Magdalen Shallows with relatively smooth bottoms should be relatively homogeneous in their response, whereas Misaine Bank, with its rough bottom and irregular sediment stratigraphy has a highly variable bottom response.

2.4.3 Resolution Required

The resolution chosen is very low. The aim is to provide a simplified picture of the area by identifying subregions as broadly as possible, and bound-

aries where drastic changes can be expected. The main characteristic of some of the provinces is their inherent high variability over small distances and lack of constant features.

2.4.4 Data Set

The physiographic provinces are determined using the bathymetry in Section 2.1, and the surficial geology characteristics (Section 2.2 and 2.3) for the area under study.

2.5 False Targets

There are two main categories of features likely to produce a false target on active sonar and MAD:

- Geological features - Bottom features such as a rock outcrop can be perceived as a target by sonar or MAD systems and must therefore be identified.
- Wrecks: - Wrecks, particularly metal wrecks, can also be perceived as targets on active sonar and MAD.

2.5.1 Impact on ASW

Disruption of operations, and waste of effort are the obvious result.

2.5.2 Variability

There is a high degree of variability between the various false targets depending upon their size and composition, as well as the type of sensor used

and its mode of operation. In addition, the target strength of these features will be subject to variability due to the target aspect.

2.5.3 Resolution Required

The position of these features must be recorded as accurately as possible ($\sim$ 200 m) when they are discovered or when a shipwreck occurs. In addition, the aspect characteristics should be noted.

2.5.4 Data Set

Data source

See the classified appendix to this document.

2.6 Magnetic Anomaly

The earth's magnetic field varies temporally as well as spatially. These anomalies in the field can be perceived as noise on some detection systems. Two types of environmental noise are involved: those induced by ionospheric anomalies, and those caused by geological anomalies.

Ionospheric anomalies are related to solar activity. Solar storms send charged particles into space that modify the natural field. In peak years of the 12 year solar storm cycle, there are intense magnetic storms about 15 percent of the time. In quiet years, intense storm activity occurs only three percent of the time [Stefanick, 1987]. The large spatial and temporal scale of variability of ionospheric disturbances prevents its inclusion in this guide. The magnitude of their effect can be predicted from the "alpha index" issued by

Fleet Numerical Oceanographic Center (FNOC) in Monterey as part of their standard environmental tactical packages; the indexes usually cover a period of three days.

The geological perturbations due the magnetic characteristics of the bedrock on the other hand, do not change with time (at the scale considered here) and should therefore be included in a planning document.

2.6.1 Impact on ASW

As an airborne magnetometer is moved through perturbations in the earth's magnetic field, the spatial fluctuations of the magnetic field results in a time dependent signal. Large steel masses such as a submarine cause such perturbations. There are, however, other sources of perturbations such as geological noise and micropulsation activity caused by an increase in cosmic particles (sunspot or aurora) and ionospheric currents that will increase the false alarm rate. The MAD system's bandpass filters are designed to admit a band of frequencies that includes the submarine signal while excluding the usually low frequencies generated by anomalies in the natural magnetic background as a result of geologic features. However, when the frequency components of the magnetic environment approximate those of the submarine signature, the target detection becomes difficult. The position of geologic features with such properties should therefore be identified.

2.6.2 Variability

Generally, continental shelves have low magnetization and are, therefore quiet [Nelson, informal communication]. Experience has shown however that

noise induced by geological features can be quite significant in some areas. In addition, areas with strong topographic features such as steep slopes are known to cause disturbances in the MAD signal.

2.6.3 Resolution Required

Submarine-like targets cause spatial perturbations of the order of 1 km. The spectral content of the signal depends on the speed of the aircraft; for a fixed wing aircraft (CP-140), it tends to be in the .01 - 0.5 Hz band, and for a helicopter (Sea King) .005 - 0.25 Hz. The data are usually filtered from 0.1 - 0.8 Hz to remove as much noise as possible.

In order to be able to recognize that type of signature, we need data points with a spacing of approximately 200 m.

2.6.4 Data Set

Data sources

There are two sources of data available: marine magnetic measurements and aeromagnetic data sets. The data gathered up to 1975, have been analyzed and compiled by Haworth and MacIntyre [1975] in a Marine Science Paper from the Geological Survey of Canada (Paper 75-9). More recently, Verhoef and Macnab [1987] have compiled all the data to produce an updated 1: 5,000,000 chart covering the entire continental margin of eastern Canada.

Technique used

The marine data were collected during bathymetric surveys, and as such the line spacing was 2 km or less in shallow areas of the continental shelf. The rate of sampling was ten times a minute, and the average value and the mean position was recorded for each minute [Verhoef and McNab, 1987]. The aeromagnetic data were collected using various flight line spacings: 1 km in some areas near shore, 2 or 4 km over most of the shelf, and 6 km over the continental slope.

The first step used to produce their map was to convert the data into a regular grid of data points. This produced the immediate disadvantage that along track details with wavelengths shorter than the mean track spacing were lost. Contours were then drawn within the grid squares. The overall filtering effect of the griding routine was the attenuation of the short wavelength anomalies that may yield false contacts or increase the noise.

Resolution

The required resolution ($\sim$ 200 m) is met along the survey lines, but not across the lines. The results obtained can thus be very incomplete and even misleading.

There is doubt as to the usefulness of these charts for ASW purposes. A more accurate approach would be to acquire the original survey data and apply a MAD filter simulator algorithm to it. The cost in time and money required to do this is beyond the resources of this project. The product that could be obtained, although better, would still be incomplete and misleading

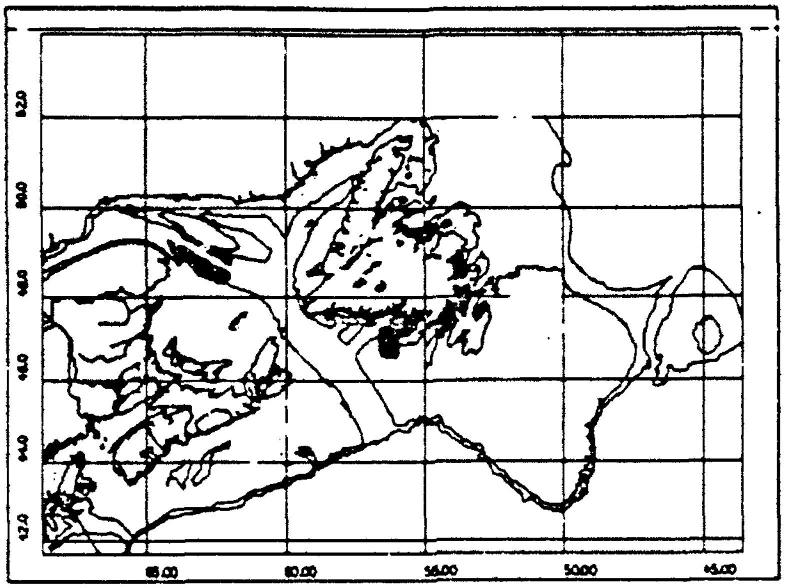

Figure 2.6: Magnetic anomaly survey coverage (Hatched areas are not covered by the existing data set).

since it would only identify areas of perturbation along the survey lines; strong gradients in the field along different axes would be missed.

Data coverage

The existing data cover most of the shallow water area of the east coast with the exception of a gap south of Anticosti Island and an area within a distance of approximately 25 km around the French islands of St. Pierre and Miquelon (Fig. 2.6).

Chapter 3

Climatology

Climatological factors can have a strong impact on the feasibility and success of operations at sea. Bad weather can result in a severe degradation in the performance level of most sensor and weapon systems, and that of the personnel operating them which makes the conduct of operations difficult, or nearly impossible. The purpose of the climatological data included in this guide is to assist planners by providing an overview of the weather conditions that they could expect in the region of the Canadian east coast at the time of the year that they are to conduct operations.

3.1 Canadian East Coast Climatology

The weather patterns at mid-latitude locations show a marked annual cycle. In the winter, a sharp contrast between the airmass over the continent and that over the Gulf Stream gives rise to a strong frontal zone just offshore along the east coast of the United States (U.S.). It is along this frontal zone that most winter storms which affect the area under study, develop. Typically, these developing lows track northeast across the Scotian Shelf and the Grand

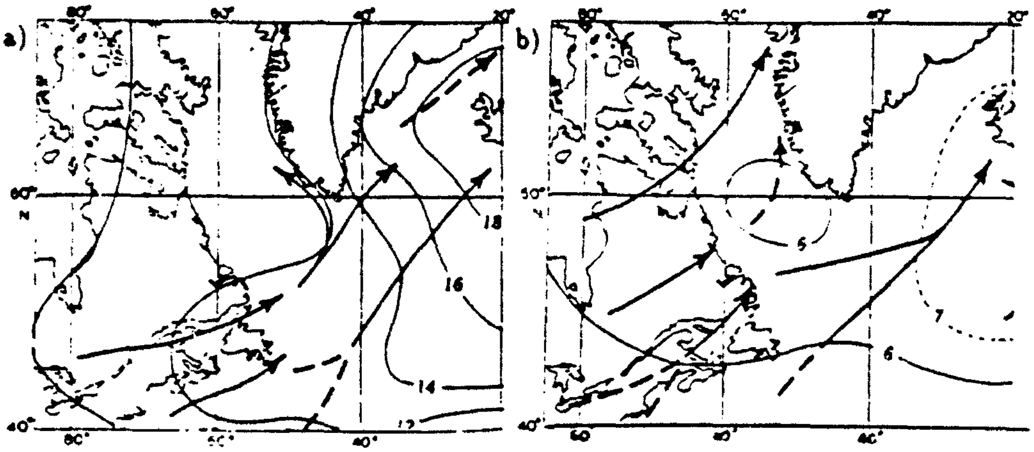

Figure 3.1: Storm tracks over the east coast of Canada in a) January, and b) July. Solid line arrows indicate tracks along which the maximum concentration of individual storm centre paths has occured. Dotted lines are secondary tracks reflecting a moderate concentration of storm paths. (From Meserve, 1974)

Banks (Fig. 3.1). The approach of these storms brings strong winds and heavy rain and snow. Following the passage of the systems, outbreaks of cold air develop in the strong northwesterly flow. Further snow can be expected as the cold air mass becomes unstable over open water. A second common storm track carries systems in from a more westerly direction. On average, the spacing between these winter storms is three to six days.

The frequency and intensity of these low pressure systems decrease with the onset of spring when a southerly flow gradually develops and advects warm, moist air from the Gulf Stream northward over the Scotian Shelf and the Grand Banks. Since the surface water is still cold, the moist airmass cools when it comes in contact with the sea surface and extensive regions of thick fog and low stratus cloud are formed, particularly over the Grand Banks. These fog

banks can persist for days or even weeks until the flow changes to bring in cooler, drier air.

During the summer months, low pressure systems are at a minimum in frequency and strength. By late summer, the occasional passage of tropical storms and hurricanes in the area is the dominant feature. These systems are formed over the warm waters of the tropics. However, storms that turn away from the U.S. east coast before making landfall can track northeastward and cross the Grand Banks (Fig. 3.2). As they leave the warmer water and are thus cut off from their energy source, these tropical storms weaken rapidly. However they can still contain some very strong winds and heavy convective rains when they reach the Canadian east coast. These storms are infrequent, with perhaps one or two crossing the Grand Banks each season. As fall progresses, the low pressure system activity starts to increase again.

3.1.1 Marine Climatology Data Sets

The process of collecting good quality weather data in adequate spatial and temporal detail, over the vast expanses of the ocean is not a trivial matter. The most commonly used data sets in marine climatology are the following:

- Observations from ships: This data set consists of observations taken at relatively consistent intervals as ships make their passage. It is based on a compilation of marine meteorological observations obtained from ship logs and weather report forms, automatic buoys, and teletype reports. The data set extends back to the mid 1800s. From the 1800s to 1979, it contains observations from all the cooperating nations and from a wide

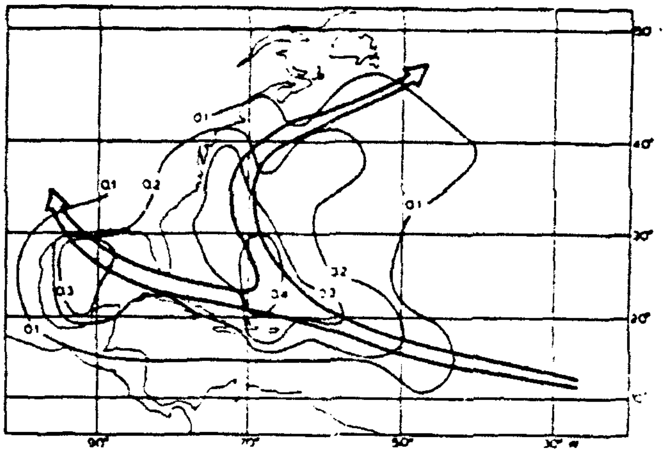

Figure 3.2: Preferred tracks and mean frequency of tropical storms and hurricanes per 5° square during the period of 11-20 September from 1899 to 1971. (After Crutcher and Quayle, 1974)

range of vessels. Since 1980, it has been updated only with observations from Canadian cooperating ships and drilling units.

- Shore station data (e.g., Sable Island and Grindstone): This consists of high quality observations made by well trained observers. Their weakness arises from the difficulty to extrapolate this "land-based" information to offshore areas [Swail, 1985].

- Weather ships: This data set is often considered the best source of marine data due to the high quality of the data collected. Unfortunately, none of these ships has been located in the study area.

- Drilling Rigs: Observations from drilling rigs are generally of good quality. The spatial and temporal coverage they provide is however very

limited. These observations are included in the ships database.

- Satellites: The remote sensing of weather data using satellites is a technique that has enormous potential, but is still in development, and contributes only for a small portion of the long term database. It offers the advantage of providing a synoptic coverage of large areas [Pickard and Emery, 1982].

- Hindcast Models: This method is limited to parameters such as wind and will be described further in the appropriate section.

The transient ships or ships-of-opportunity data set has been used for the analysis of most of the parameters that describe the Canadian east coast climate in this document.

Quality and coverage

The ships' observations are the most important source of data. They also cover the longest period, more than 100 years in the case of some parameters. The main deficiency of this type of data is that it is not consistent spatially or temporally since most observations are taken near major ports or along main shipping routes. In addition, ships understandably tend to avoid bad weather which results in a "fair weather" bias in their observations. The instrumentation used, its precision and location on the ship, as well as the observer's qualifications vary from ship to ship [Mortsch et al., 1985].

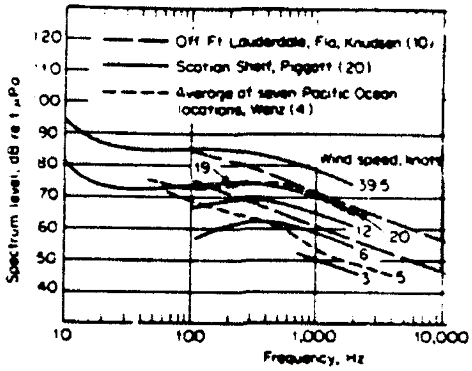

Figure 3.3: Noise spectra with wind speed as a parameter from measurements taken at coastal locations. (After Urick, 1983)

3.2 Wind

The wind is an important environmental parameter. It generates waves and currents, influences the windchill and the occurrence of freezing spray, and thus has a strong impact on the effectiveness of crew and equipment during operations. Strong winds may prevent helicopter operations at sea, create dangerous conditions for people on decks and hamper rescue operations.

3.2.1 Impact on ASW

The wind blowing over the sea can produce many dramatic effects in terms of acoustic transmission. Piggott [1965] showed the dependence of the ambient noise level on wind speed at all frequencies between 10 and 3000 Hz (Figure 3.3). He found an increase in the noise level of 7.2 dB each time the wind speed doubled. There also is an increase in the attenuation of underwater signals which can be very large. Weston and Ching [1988] reported transmission losses in the shallow water of the North Sea in excess of 40 dB (at 4.4 kHz) in the presence of high winds. The mechanisms responsible for this increased

attenuation are assumed to be:

- Reflection and scattering of sound by the rough sea surface caused by wind.
- Absorption and scattering of sound by entrained gas bubbles
- Breaking up of fish schools.

3.2.2 Variability

Based on the general climate description given earlier, a high variability can be expected at the seasonal scale, and at the synoptic storm scale (three to six days). Important spatial variations can also be expected, in particular between offshore and inshore areas. At smaller scales, the wind can vary substantially over a height of only a hundred metres and a distance of a few kilometres. At these scales, there are wind gusts of various duration, strength and frequency.

3.2.3 Resolution Required

The data must reveal the dominant seasonal wind pattern and its degree of variability. Given the high variability of the climatology for this area, averaged monthly or at least bi-monthly information is required.

3.2.4 Data Set

The data sets used to determine the wind field are held by the Canadian Climate Centre of the Atmospheric Environment Service and are as follows:

Ship-of-opportunity: The ships' data set (described in Section 3.1.1) has been used to compute the mean wind speed and direction, and the frequency of

storms and gales.

Geostrophic wind climatology (GWC): This data set is used to determine extreme wind speed and duration statistics. The data set is a 33 year hindcast of wind speed and direction using a long time series of surface pressure synoptic maps. From these maps, a gridded pressure data set is calculated from which the geostrophic winds are obtained.

Data Quality

Ship-of-opportunity data: Some inherent weaknesses of the ships' data set are described in Section 3.1.1. There are also some specific problems associated with the wind data collection. The wind data are obtained either by estimation from the sea state using the Beaufort Scale or by measurements using an anemometer. The accuracy of the former method depends on the experience of the observer, whereas for the later, it depends on the type of instrument, its precision, and its location on the ship. Furthermore, the data set is inadequate for extreme value analysis and duration statistics since it is a collection of individual observations taken irregularly at a variety of locations which represent a finite area rather than a point. Time series analysis requires a long continuous record of data from one location [Swail, 1985]. Nevertheless, studies show that on average, the data from ships do represent the wind field reasonably well [Quayle, 1974].

GWC data: The accuracy of the results of the hindcast model is dependent upon the quality of the pressure data used. It is therefore likely to be rather variable, since the number of pressure observations from ships are highly vari-

able in time and space. The results may be less reliable away from shipping lanes, in mid-ocean areas, and more accurate near higher quality data sources such as oil rigs.

Based on some comparisons with weather ship data, the geostrophic wind appears nevertheless, to be a good first approximation to the true surface wind. It is also suitable for statistical analysis such as persistence and extreme value analysis, thus complementing the ships' data set.

3.3 Flying Weather

Aircraft are used extensively in ASW operations. Bad weather can severely restrict their use, particularly at low levels. Weather conditions affecting low level flying (cloud ceiling and visibility) have been summarized and categorized into three types commonly used in aviation: Visual Flight Rule (VFR), Instrument Flight Rule (IFR), and below IFR.

3.3.1 Variability

On a seasonal basis, we can expect the variability in flying conditions during winter to be related to the passage of the low pressure systems which cause large fluctuations in cloud cover type and precipitation. In spring and the beginning of summer, the poor visibility associated with the formation of fog banks is responsible for an increase in the occurrence of below IFR conditions. The visibility and cloud cover are usually uniform over large areas when the weather is good. However, the visibility may vary substantially over small areas when there is precipitation, and the reported visibility conditions

may not persist for long periods.

3.3.2 Resolution Required

Representative seasonal conditions should be described.

3.3.3 Data Set

The ship-of-opportunity data set is used. Flying weather depends on ceiling height, type and amount of cloud cover, and visibility. Visibility has been estimated from ships since 1860 whereas cloud cover characteristics have been recorded since 1939. Cloud cover can be either estimated or measured.

Data quality

The data set is subject to the sources of error and bias generally associated with ship-of-opportunity observations (Section 3.1.1). Since the parameters used (ceiling and visibility) are usually estimated instead of measured, the experience of the observers is a *critical factor* in the accuracy of the data collected.

3.4 Visibility

In addition to its importance in determining the prevalent flying conditions, visibility is obviously an important factor for the safe navigation of a ship, in particular during covert tactical operations when the use of other navigation systems (e.g., Radar) is denied. The visual detection or identification of targets is still an important tactical tool even in this age of "high-tech" sensors.

3.4.1 Variability

As described in Section 3.3

3.4.2 Resolution Required

Some representative seasonal conditions should be described.

3.4.3 Data Set

Same as in Section 3.3

3.5 Air Temperature

The air temperature determines the operating conditions for personnel working outside, and may impose restrictions on the use of some pieces of equipment. Vertical profiles of air temperature are also required to identify areas where anomalous electromagnetic propagation (e.g., radar ducting) could occur.

3.5.1 Variability

These mid-latitude regions are subject to large surface temperature fluctuations over the year with the extremes ranging from -30° C in winter to 30°C in summer. At smaller time scales, temperature is not normally subject to large variations in a given area, except near the shore or near a front.

3.5.2 Resolution Required

The representative seasonal conditions should be described.

3.5.3 Data Set

Surface air temperature measurements from ships have been recorded since 1855. Data sets on vertical temperature gradients over the ocean are virtually non-existent [Swail, personal communication].

Data quality

Air temperature measurements should be made with a thermometer which is properly shielded from direct solar radiation. The location of the thermometer used for measurements on ships is therefore a major source of error in air temperature measurements.

3.6 Precipitation

The amount and type of precipitation contribute to low visibility conditions. In cold weather, precipitation may result in hazardous icing conditions.

3.6.1 Impact on ASW

Precipitation, in particular falling rain, increases the ambient noise levels. The increase depends on the rate of rainfall and on the area over which the rain is falling. Heavy rain can be so loud that it dominates the wind noise. Table 3.1 gives some estimates of noise caused by moderate and heavy precipitation.

3.6.2 Variability

The frequency of precipitation is higher during winter since synoptic storms are more frequent. Depending upon the season, the predominance

Rain Intensity	Frequency (Hz)					
	40-100	100-200	200-500	500-1000	1000-2000	2000-5000
Moderate	60	65	65	65	70	65
Heavy	70	75	75	75	75	70

Table 3.1: Estimates of ambient noise due to rain for moderate and heavy rain conditions. Values are in dB re 1 μPa^2 in 1 Hz band. (Source: Urick, 1975)

of the form of precipitation (drizzle, rain, ice pellets, snow or hail) will vary. Spatially, there will also be large variations in the amount of precipitation in showers.

3.6.3 Resolution Required

Representative seasonal conditions should be described.

3.6.4 Data Set

The ship-of-opportunity data set is used. The observations are mostly visual estimates, categorized as light, moderate or heavy precipitation.

Data quality

The available information provides only a qualitative description of the precipitation characteristics. It includes an overview of the frequency of different types of precipitation, but no information on the amount of precipitation involved. This is nevertheless sufficient for most of the present needs.

3.7 Sea Ice

The presence of sea ice is controlled by the climate in a region. In return, the sea ice cover once in place, has a strong impact on the local and regional climate. A sea ice cover constitutes a sensible heat and moisture barrier between the atmosphere and the ocean since its high albedo effectively reflects most of the incoming solar radiation and it acts as a thermal reservoir that delays the seasonal temperature cycle. Additionally, salt is forced out of the sea ice when it freezes and hence the water salinity will be affected as well as the vertical stability of the water column.

3.7.1 Impact on ASW

Sea ice is a very important limiting factor for ASW operations. It negates the use of most ASW ships since few are designed to navigate in ice; the effectiveness of ASW aircraft is drastically reduced, and the presence of ice cover restricts submarine manoeuvres as well.

The presence of ice can have a strong impact on ambient noise levels since it results in different mechanisms for ambient noise generation. Measurements made by Payne [1964] in the Magdalen Shallows shows that the ambient noise can be as much as 20 dB less under a continuous ice sheet. When there is ice movement however, noise levels will be as high as in open water. The noisiest sector is the zone between continuous pack ice and ice free waters. In this zone the noise can be up to 10 dB higher than for ice free water [Urick, 1983].

MacPherson [1964] noted that smooth young ice will have a relatively small effect on the propagation, whereas old ridged ice will result in much higher

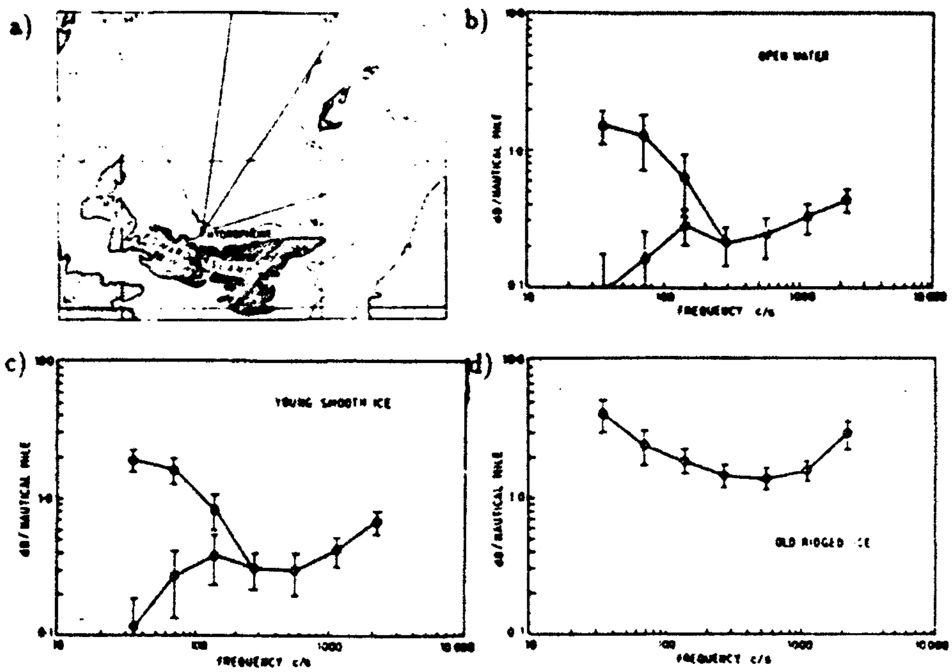

Figure 3.4: Attenuation coefficients measured at a) a location north of Prince Edward Island, b) under open water conditions (January), c) under young smooth ice, and d) under old ridged ice conditions. The use of two curves in b) and c) is explained in Section 3.7.1. (From Macpherson, 1964)

propagation losses. Figure 3.4 shows the attenuation coefficients measured in open water and under different ice conditions. (The double values at low frequencies in part b) and c) are due to different attenuation coefficients measured at different ranges from the hydrophone. At short ranges, higher order modes predominate which cause large values in the attenuation coefficients whereas beyond 30 nm, only the first mode is important which results in the lower values.)

3.7.2 Variability

The extent of sea ice (away from land) is determined by a balance between atmospheric and oceanographic factors. Depending upon these factors, sea ice cover can vary considerably from year to year at a given location. Although the variations for given areas can be quite large, they tend to compensate each other during a particular period. As a result, the total area of sea ice cover over the hemisphere does not change significantly from year to year [Agnew, 1990].

3.7.3 Data Set

Ice data were obtained from the Ice Centre of Environment Canada. Ice information gathered from observations is used to produce weekly charts depicting the ice cover off the coast of eastern Canada. Such charts covering 25 years of records from the season 1962/1963 through 1986/1987 were used. Ice edges observed at the same date (or on the chart dated most closely to the selected date) over the 25 years were analyzed to produce maximum, minimum and median ice limits. The median ice limit refers to the line along which ice has been reported 50 % of the time during the 25 year period.

Data quality

The data are adequate to provide an overview of the ice climatology for this portion of the east coast of Canada. The maximum and minimum ice limits shown indicate the variability of the ice cover limit. The fact that these ice limits are not representative of any real ice season, but are a composite of

all twenty-five years should however be noted.

The main limitation of these data is that the information concentrates on the ice edge position only, and no information is given on the ice concentration within the pack.

3.8 Icebergs

The presence of icebergs will always be a serious hazard to navigation. Most of the icebergs found in Canadian waters are from the glaciers of western Greenland.

3.8.1 Variability

Icebergs vary in size from 15 m long and 1.5 m high (small berg) to over 220 m long and 100 m high (very large berg). Smaller chunks of ice calved by glaciers are called bergy bits and growlers. Estimates of the average annual production of medium or large sized icebergs in Greenland range up to 40,000 while only some 300 to 400 reach the Grand Banks [Murray, 1969]. Significant variations have been observed with the numbers ranging from as high as 2,200 in 1984 to none in 1966 [AES, 1985]. Iceberg movement is controlled mainly by water currents, although for high sail to draft ratio, wind can become important. The average velocity east of Newfoundland is 20 cm s^{-1} [AES, 1985]. A few icebergs drift through the Strait of Belle Isle, but their number is reduced by the limiting depth of 50 m and the narrowness of the entrance. South of Newfoundland, icebergs are most frequent from March to July.

3.8.2 Data Set

Data on icebergs for the east coast of Canada are available from the Ice Climatology and Applications Division of the Atmospheric Environment Service. The International Ice Patrol has completed iceberg censuses since 1945.

3.9 Icing

Ice accretion can create dangerous conditions for a ship at sea, and it must always be prevented on aircraft, especially on helicopters. On ships, accretion of ice causes hazardous conditions for the crew, because of the resulting slippery conditions and risk of falling ice; but the primary danger comes from the additional load this ice constitutes, and the increased surface area for the wind and waves to act upon. Ships with such a load become difficult to manoeuvre, top heavy, and prone to capsizing. For aircraft, ice accretion modifies the shape of airfoils, and thus reduces their lifting capacity. Icing also changes the weight distribution and very seriously affects the takeoff and landing capabilities. Three main phenomena that result in ice accretion on exposed surfaces can be distinguished [Mortsch et al., 1985]:

- Rime or clear icing in clouds: Rime ice is opaque ice that forms when discrete supercooled water droplets in clouds or fog strike a sub-freezing surface. It creates dangerous conditions for aircraft, particularly helicopters. Very little data are available on rime icing over the ocean. It cannot therefore be included in this guide.

- Freezing precipitation: Freezing precipitation includes freezing rain, freezing

drizzle and even wet snow. The resulting accumulation is proportional to the droplet size, therefore, freezing rain is the most serious in this category.

- Freezing spray: Freezing spray occurs when cold sea water is whipped by the wind into a flying spray through the air onto a sub-freezing metal surface which results in a layer of ice being formed. It is the most dangerous source of icing.

3.9.1 Variability

The actual ice accumulation on a vessel can vary considerably depending upon several climatological factors (air temperature, amount of precipitation, and wind speed) whose variability has been described in the previous sections. It also varies due to factors such as the vessel structure, its course or orientation to the wind, and its speed.

3.9.2 Resolution Required

Areas where ice accretion may affect operations should be identified. Monthly climatology should be adequate.

3.9.3 Data Set

Freezing precipitation: The data set used is based on the assumption that freezing precipitation occurs when the observed temperature is less than zero degrees Celsius, and rain or drizzle is occurring. The data also include the occurrences where the weather report mentions freezing precipitation. The observations are from the ship-of-opportunity data set.

Freezing spray: The potential for the accumulation of ice due to freezing

spray is calculated from the observed conditions of sea surface temperature, air temperature, wind speed, wave height and salinity. The relation of these factors is translated into an empirical rate of ice accumulation.

Data quality

Freezing precipitation: The occurrence of freezing precipitation coded as light, moderate, or heavy precipitation is reported, but measurements of the amount of precipitation or accretion are seldom made. It is therefore difficult to quantify the resulting amount of ice accretion.

Freezing spray: Because of the lack of observed measurements of freezing spray, the " freezing spray potential" is used. This empirical method [Kachurin et al., 1974] which relates atmospheric and oceanographic parameters to icing rates has not however been thoroughly validated by a comparison of the results and the actual accretion measurements. It is also subject to the limitations of the input data.

Chapter 4

Oceanography

The oceans are the environment of the submarine; the knowledge of the physical properties of its constituent water masses is essential in order to effectively use ASW systems. The effective use of acoustics systems in particular, requires the knowledge of temperature and salinity distributions, and hence sound speed, in order to determine how and where the acoustic energy will propagate. The motion taking place within these water masses, the presence of currents, can affect sound propagation, low frequency noise, as well as ship navigation and can influence tactics. The state of the surface boundary, the sea surface, also strongly influences ASW operations. The performance of acoustic sensors as well as other sensors such as radar and MAD is closely related to the sea state.

4.1 Waves

Much effort has been spent attempting to improve the knowledge of wave climatology on the east coast of Canada. These efforts have been motivated mainly by the requirements for the safe design of offshore facilities for oil

exploration and production. Although the safety of the platforms involved in ASW operations would not normally be a concern, since the ships' designs allow them to survive extreme conditions, the effectiveness of the crew and of the equipment can be severely degraded in high sea states.

4.1.1 Impact on ASW

In terms of ASW, wave characteristics although not as critical as for oil exploration and fishing activities, have nevertheless a strong impact on operations due largely to their impact on the performance of acoustic systems.

Waves affect acoustic systems in many ways. First, in shallow water, the acoustic energy propagates via repeated reflections from both the sea surface and bottom. Therefore, the roughness of both the bottom and the sea surface are important determinants of the sound field. When the sea surface is flat, it acts as a mirror and reflects the sound energy in a coherent manner [Urick, 1983]. If the surface is rough, it acts as a scatterer and sends incoherent energy in all directions. Second, air bubbles formed by the breaking of waves and carried by turbulence beneath the surface can have a strong effect on the scattering and the absorption of the sound energy. Third, ambient noise in the band 0.5 to 50 kHz is directly associated with the sea state and the wind in a given area [Brekhovskikh and Lysanov, 1982]. Furthermore, breaking waves are a significant source of low frequency noise through the process of "coherent oscillation" [Pumphrey et al., 1990].

Finally, high sea state conditions may prevent the deployment or retrieval of towed sensors, and also degrade the effectiveness of sensors such as ASW

radars and MAD by increasing noise, display clutter and false alarm rate.

4.1.2 Wave Climatology

Since ocean waves are generated by the wind, it follows that we can expect the wave climatology to be similar to the annual cycle of synoptic scale storms with both the average sea state and its variability at a maximum in winter and a lowest in summer.

4.1.3 Resolution Required

The resolution required for wave data in this guide should be sufficient to provide a good description of the average monthly conditions and their degree of variability for each of the main regions.

4.1.4 Data Set

When dealing with wave information, there are usually two basic types of data considered. The first, wave climate data or the statistical description of the frequency of occurrence and persistence of individual wave parameters or joint distributions of two or more wave parameters will be covered here. The second type, extreme waves, indicate the wave height that should be exceeded only once in a given period of time (e.g. 100 year wave height). They require only the knowledge of the largest wave heights in the more severe storms [Cardone et al, 1989]. Extreme wave values are essential to determine design criteria of offshore structures but are not required here. However, some statistics on the duration of storms and their associated high wave conditions are of interest.

Data acquisition

There are four methods by which information on waves is usually obtained:

- Hindcast from wind observations: Models are used to generate a wave climate based on observed winds or from pressure fields.
- Direct measurements with accelerometer buoys, wave gauges or bottom pressure gauges.
- Aerial surveys from aircraft or satellites: This is an area that has a high potential, but is still in development and presently contributes only a small portion of the long term database. The method offers the advantage of giving a synoptic coverage of large areas [Pickard and Emery, 1982].
- Visual observations from ships: These data are extracted from ship logs or ship weather report forms. It represents the most important source of data and also covers the longest period, going back to the 1800s. The main limitation of this type of data is that it is neither consistent spatially nor temporally. Most observations are taken near major ports or along shipping lanes. In addition, ships understandably tend to avoid bad weather, which results in a "fair weather" bias in their observations. Observer qualifications also vary greatly. It should be noted that "visual" wave heights have been calibrated against other sources to confirm that they do give a valid representation of the significant wave height [Mortsch et al., 1985].

The wave data used in this guide have been obtained from ships-of- opportunity. Most of the data used in this guide has been compiled in the Marine Climatological Atlas -Canadian East Coast from the Canadian Climate Centre [1985].

Resolution

The data in hand are adequate to provide an outlook on the conditions that could reasonably be found in the given area for each season.

4.2 Currents

4.2.1 Impact on ASW

Beyond their importance for navigation which is not covered here, currents can have a marked influence on ASW operations. They contribute to the formation and modification of water masses as transport and mixing agents and are responsible for the generation of ambient noise in the infrasonic portion of the spectrum [Zakarauskas, 1986]. Their presence can also significantly perturb the trajectory of sound rays [Sanford, 1974]. Finally, some currents could possibly be exploited tactically by submarines.

4.2.2 Types of Currents

Information on the mean currents and their variability at different scales is required. Seasonal variability is particularly important, since seasonal changes in the forcing mechanisms are significant and therefore result in large modifications in the current patterns.

Mean surface current

These currents depend mostly on wind forcing and freshwater runoff. Mean surface currents are important since they often carry water with physical properties different from those of the surrounding waters, and are sometimes associated with strong fronts that can drastically perturb the sound propagation path. The knowledge of their location and strength is also required to predict the drift rate of sensors such as sonobuoys.

Subsurface circulation

These currents generally refer to the flow in the region below the mixed layer caused by tidal and geostrophic circulation. Regions of persistent strong current shear at depth exist in Canadian waters, predominantly near the shelf break. Sanford [1974] has shown that the presence of a current shear at any level can significantly perturb the sound propagation path. This can result for example, in longer detection ranges when the sound propagates against the current than when it propagates in the direction of the current.

Tidal currents

Tides result from the attraction of water particles on the earth's surface by the sun and moon. The difference in gravitational forces resulting from the change in position of these celestial bodies relative to the earth's surface causes variations in sea level that propagate around the earth's oceans as very long waves.

The tides and their resulting tidal currents become stronger near the coast

as water depth decreases, and consequently, they play an increasingly important role in the local circulation. In fact, in coastal waters, tidal currents are usually much stronger than the mean flow and they are responsible for the large fluctuations in the observed water motion. In narrow waterways, such as the Gulf of St. Lawrence or the Bay of Fundy, the common pattern is a flood current as the tide rises and an ebb current in the opposite direction as the water falls. In more open ocean waters, such as over the continental shelf, tidal currents are rotary and the water particles tend to follow the path of an ellipse during one complete tidal cycle. The major axis of that ellipse will tend to become more or less parallel to the shore as the shoreline is approached [Knaus, 1978].

Garrett et al. [1985] have also shown that tidal currents can be an essential factor in the short-term prediction of iceberg tracks in the Grand Banks area.

4.2.3 Variability

It can be said that the dominant characteristic of the water motion is its variability, and the multiplicity of space and time scales over which it occurs. The variability of currents depends on the variability of the forcing mechanisms, the topography and the bathymetry. For surface currents wind and freshwater runoff are the main forcing mechanisms; both are highly variable and therefore, these currents can be expected to present the same degree of variability. Tides are caused by the interaction of several celestial bodies, resulting in high variability in the forcing which however can be precisely calculated from the predictable motions of the bodies. Tidal currents, as well as

subsurface currents, are also affected by coastal and bottom topography which again are highly variable in this area.

Temporal variability: Seasonal changes in the weather such as changes in the prevailing winds and in the amount of freshwater runoff combined with seasonal variations in the strength of the density driven currents result in seasonal current fluctuations (periods longer than about 30 days). At slightly shorter scales, winds from cyclical storms, continental shelf waves, meanders and baroclinic instabilities all contribute to displace and change the large-scale currents that affect a given site. Finally at periods of a few hours, to about one day, tides and storm generated currents may cause large variations in current strength and direction.

Spatial variability: Variations in the topography play the most important role over a wide range of scales while freshwater runoff plays an important role in more localized areas such as the mouth of the St. Lawrence. At scales of a few tens of kilometres, tides and storm generated currents are present.

4.2.4 Resolution Required

The knowledge of the main features of the circulation is required, i.e. strong currents and currents responsible for large water mass exchanges, as well as their degree of variability.

4.2.5 Data Set

Over the last twenty years, several studies have focused on the water circulation in this area. These studies occurred at different times, over areas of various size, over various periods of time and using a wide variety of

instruments.

Current determination

The main tools used by oceanographers to derive information on circulation and currents are:

- Moored current meters (Eulerian measurements)
- Drifting buoys (Lagrangian measurements)
- Geostrophic calculations from temperature-salinity observations
- Modelling or predictive techniques.

All these methods and instruments contribute in varying degrees to the determination of currents in different parts of the Canadian east coast.

Actual measurements of currents are obtained using current meters and drifting buoys. Moored current meters record current speed and direction as a function of time at selected depths and locations. Drifting buoys provide information on water trajectories at the surface or at depth. Even ships drift can be used to obtain information on currents. These current records contain the composite signal of various types of water motion which must be separated:

- Large-scale currents (overall circulation)
- Mesoscale currents
- Wind-driven currents
- Tidal currents

The relative importance of each component is usually determined by spectral analysis of the data. These methods provide invaluable information, but even for a relatively small area (on the ocean scale), the number of such instruments and the effort required to obtain a complete synoptic picture for the whole area, for the whole year, and over a time span sufficiently long to obtain a meaningful average is immense.

In order to fill the gap in the database, other methods, such as geostrophic calculations and modelling are used. The geostrophic calculation infers current from gradients in the density distribution. The assumption is that the motion is a result of the balance of the pressure and Coriolis forces. In addition, mathematical modelling permits the extrapolation of the knowledge gained through observations to regions or time periods where data are less abundant or non-existant.

Resolution and quality

It is generally assumed that geostrophic calculations depict currents which vary slowly in time and are part of the long term circulation pattern. The main limitation of the mean geostrophic currents, is that they provide only the roughest guide as to where major currents may be located and their average flow speed. They account for only a fraction of the total flow and reveal nothing of the variability of the flow over time scales of less than a few days to weeks.

Since the expected tidal range and its associated circulation is based on predictions using measured data from shoreline stations, tidal currents are rea-

sonably well known near the coast where the measurements are taken and in areas where the tide has a strong influence like the Bay of Fundy. A problem arises however when attempting to interpolate tidal currents between measurement sites since the bathymetry of the continental shelves, and the coastal landform, produces strong spatial variations in tidal flows. These data are not necessarily representative further offshore either. But since the tidal range decreases away from shore, the lack of precise data for offshore locations is not as important.

Due to the nature and expense of the research projects that have taken place over the years, direct current measurements tend to be concentrated in specific areas with little coverage elsewhere [Gregory, 1988].

However, the data do allow one to identify the main features of the circulation, especially those that are likely to have the strongest impact on ASW operations. Nevertheless the data do not present a complete statistical description of the water motions and their variability at all locations over the area.

Coverage

Overall, the most important features of the ocean circulation are reasonably well known in this area. The seasonal variability is however not well documented for regions other than the Gulf of St. Lawrence.

4.3 Sea Surface Temperature

The sea surface temperature is one of the few parameters of the water mass that can be measured completely remotely. It may be used to recognize the presence of mesoscale features and to guide appropriate action regarding in situ sampling strategy. It is also an important factor for planning search and rescue operations, since it affects human survivability in the water.

4.3.1 Variability

The yearly variations can be very large at these latitudes with the sea surface temperature ranging from $-1°C$ to 18° at some locations.

4.3.2 Resolution Required

As for most of the climatological parameters, the resolution required is rather low. Average seasonal conditions and their degree of variability is sufficient.

4.3.3 Data Set

Data sources

Several sources of data exist:

- measurements taken during meteorological observations (ships-of-opportunity);
- measurements taken during oceanographic surveys (CTD, bathythermograph);
- satellite imagery using visible/infrared radiometry.

The sea surface temperature used in this guide has been extracted from the Marine Climatological Atlas - Canadian East Coast from the Canadian Climate Centre [Mortsch et al., 1985]. In this document, the ships-of-opportunity data set was used.

Data quality

The weakness of the first two methods for measuring sea surface temperature, is their irregularity of measurements, with a total absence of data in some areas or some periods of the year. The measured data are therefore insufficient at places to define the complex patterns of the sea surface temperature which occur in this region. The measurements taken are however sufficiently accurate.

Satellites can provide a more global coverage, with an accuracy of 0.5°C and a spatial resolution of approximately 5 km [Robinson, 1985]. The weaknesses of remotely sensed data are first that the measurement is that of the "skin temperature", therefore its usefulness depends on the ability to interpret it in terms of underlying temperature of the top metre or so of the ocean; second, measurements are degraded by the presence of water vapour in the atmosphere, and finally, fog or cloud cover can prevent measurements during long periods of time .

Resolution

The resolution is low but deemed adequate for the needs of this guide.

Coverage

The sample distribution is unevenly distributed spatially and seasonally, leaving some areas undersampled at some times of the year, especially during the winter when ice cover is present.

4.4 Water Mass Distribution and Fronts

Water masses are parcels of water that can be recognized by characteristic values of some of their physical properties, in particular temperature and salinity. These properties are assumed to be relatively constant within a given water mass.

Oceanic fronts are narrow boundary zones between adjacent water masses of dissimilar properties. They are characterized by very large horizontal gradients in water properties such as salinity, temperature, density, and dissolved materials. Active turbulent mixing can occur in frontal regions.

4.4.1 Impact on ASW

Water mass identification is important since different sound propagation characteristics can be expected within different water masses. Fronts are particularly important, because of the abruptness of the changes in water properties over short distances which can cause significant refraction of the sound energy as it propagates across the front.

4.4.2 Variability

Seasonal variability is high, due to large seasonal differences in solar energy input at these latitudes and the variations in freshwater outflow. The presence of currents such as the Labrador Current which advect large quantities of cold water also has a stong impact on the water mass distribution.

4.4.3 Resolution Required

The general locations of the main water masses and fronts are required as well as a description of the seasonal variability pattern.

4.4.4 Data Set

The source of information used in this guide to show the distribution of water masses is the Ocean Features Analysis (OFA). These OFAs are charts produced twice a week by the METOC Centre Halifax and depict the most probable distribution of water masses on the east coast (Figure 4.1). These are generated from satellite infrared pictures that allow the identification of the boundaries between different types of water. Additional information such as sea surface temperature, climatological and historical data, recent bathythermographs, as well as previous OFAs are used to produce this picture of the water mass locations [R. Bigiot, METOC, personnal communication]. The set of OFAs for 1989 are included in this guide. The boundaries shown are not median or average positions for these water masses and the details of the features vary widely from year to year. The overall pattern of water mass migration is however representative of the motion taking place.

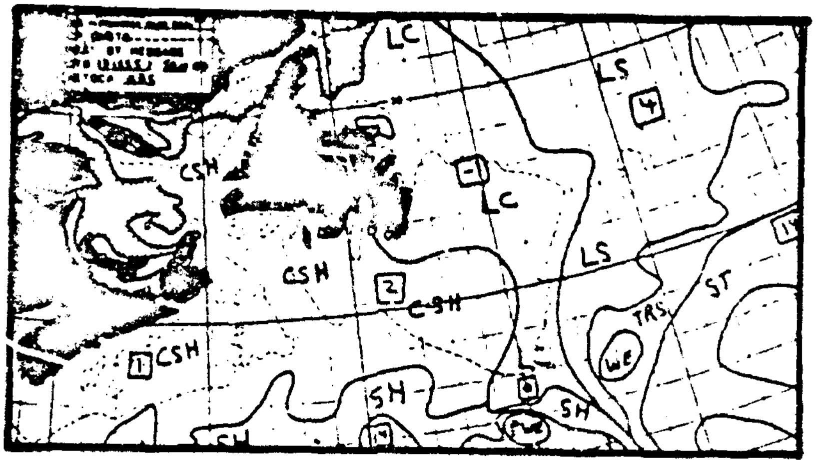

Figure 4.1: Ocean Feature Analysis.

Quality

The quality of the resulting charts depends on the effective satellite coverage that was obtained, i.e. actual sea surface coverage not limited by cloud cover or fog. The quality is also limited by the amount of in situ measurements (sea surface temperature and bathythermographs) available to "ground truth" the satellite information.

Coverage

Two satellites cover the area. This results in several passes (at least two) per day over the area of interest. Since the OFAs are produced twice a week, full coverage of the area is normally achieved for most periods of the year.

4.5 Temperature and Salinity Profiles

Temperature and salinity as a function of depth is required to compute the sound speed profile which is the most important tool for the use of underwater acoustic systems.

4.5.1 Temperature Profiles

Typical temperature profiles for different subareas of the regions under study are required. The water temperature is by far the most important variable affecting sound speed in water. Although the relation between sound speed and temperature is not linear, the approximation of an increase of 4 m s^{-1} per each $°C$ rise of temperature [Pickard and Emery, 1982] is accurate enough to allow a quick estimation of the effect of temperature changes on sound velocity. These profiles are particularly important for tactical applications since they are the main inputs for acoustic prediction models, and allow one to relate an in situ measurement (bathythermograph) to a given water mass and its acoustic prediction data.

Variability

Strong seasonal variations can be expected in the surface layer. In these latitudes, a strong thermocline tends to develop during summer which is gradually eroded during fall until isothermal conditions across the whole water column are reached in winter (Figure 4.2). During spring and summer, a diurnal thermocline can also develop.

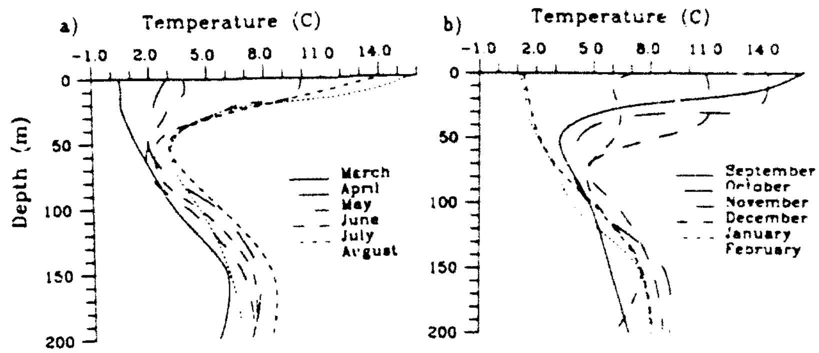

Figure 4.2: Annual growth (a) and decay (b) of the seasonal thermocline on the Scotian Shelf. (Data from Drinkwater and Trites, 1987).

4.5.2 Salinity Profiles

Salinity is the only other physical property besides pressure that affects the speed of sound in seawater in a significant manner. The relationship between sound speed and salinity although not linear can be approximated using an increase of 1.5 m s^{-1} per psu increase in salinity.

Variability

In the open ocean at mid-latitudes, salinity variability with depth or horizontally is small. These variations can usually be ignored in the calculation of sound speed for tactical applications. There are some exceptions however first, in the case of an isothermal structure through the entire water column, such as that found over most of the area in winter, the salinity variations although weak, may significantly perturb the propagation path. Salinity variations can also play a significant role in regions of important freshwater outflow

such as the St. Lawrence Estuary. Figure 4.3 shows the effect of the low salinity freshwater outflow which occurs in the spring in the St. Lawrence Estuary and results in a salinity gradient of up to 8 psu over the surface 100 m layer. In this example, it can be seen that if the same bundle of rays and the same temperature profile are used in both cases, the sound interaction with the surface is reduced in the case of lower salinity at the surface (strong freshwater outflow) which should yield longer propagation ranges, particularly for the frequencies high enough to be trapped in the duct.

4.5.3 Data Set

The data used were compiled in a series of technical reports by scientists from the Bedford Institute of Oceanography:

- No 1450 - Monthly Means of Temperature and Salinity in the Grand Banks Region (Drinkwater and Trites, 1986)
- No 1539 - Monthly Means of Temperature and Salinity in the Scotian Shelf Region (Drinkwater and Trites, 1987)
- No 126 - Monthly Means of Temperature, Salinity and Sigma-t for the Gulf of St. Lawrence (Petrie, 1990)

The original temperature and salinity data were obtained from the Marine Environmental Data Service (MEDS) in Ottawa and consisted of archived bottle data collected by various countries from 1910-1982 inclusive with approximately 85% of the data collected after 1950. Temperatures were measured using reversing thermometers and salinity was determined from bottle samples by titration methods, or in later years, using electronic salinometers. The data

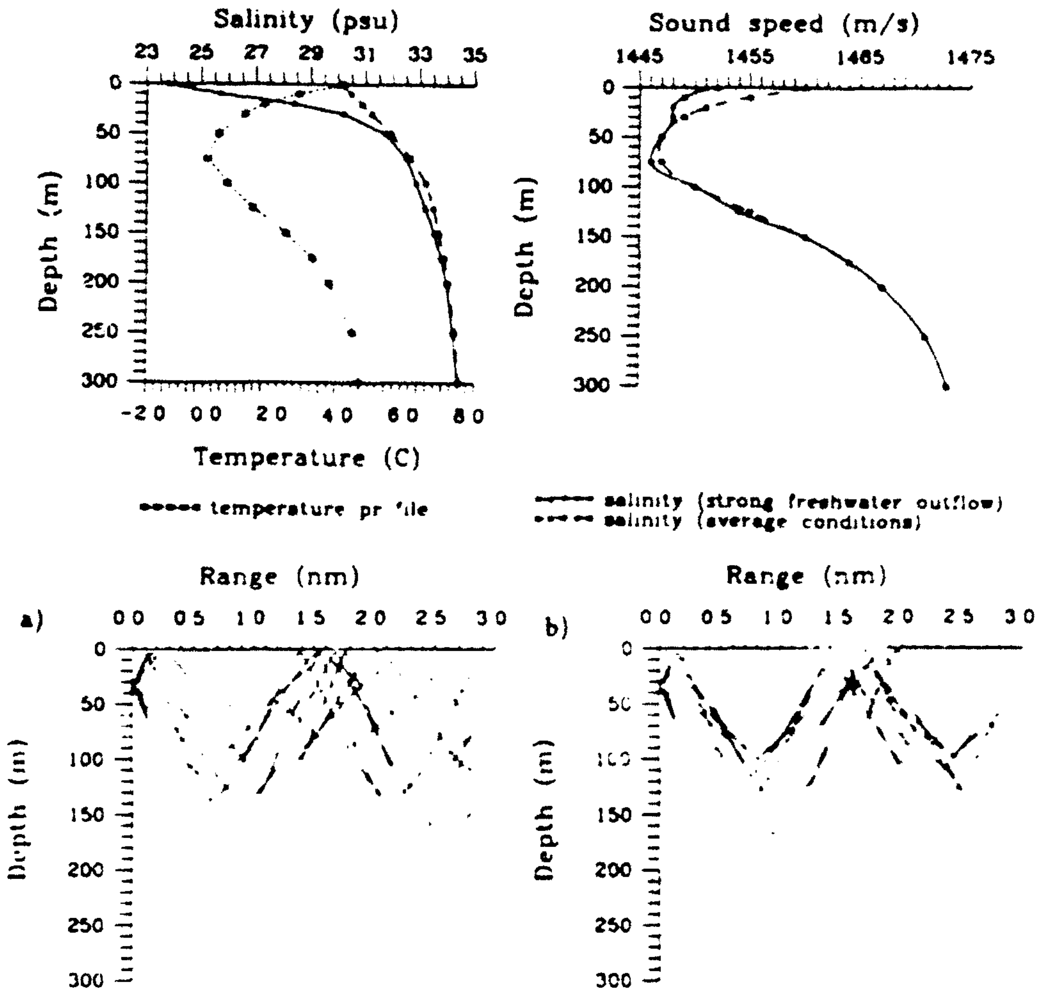

Figure 4.3: Effect of surface salinity variations due to freshwater outflow on sound propagation demonstrated by comparing the ray trace of sound energy propagating in a water column with a salinity profile typical of the St Lawrence Estuary while a) average salinity conditions and b) strong freshwater outflow exists.

were then sorted into subareas chosen to encompass specific topographic features (e.g. banks, channels, continental slopes, and basins) within which it was felt horizontal gradients of temperature and salinity may be weak. Where necessary, station data were linearly interpolated to standard depths. The data were then combined within each subarea and monthly means and standard deviations of temperature and salinity were calculated at standard depths.

Other data sets of temperature, obtained mostly from expendable bathythermographs (XBTs and AXBTs) are also available from MEDS and FNOC. These could be used to supplement the temperature data presented here.

Resolution

As mentioned earlier, the subarea boundaries were defined to minimize the horizontal gradients of the properties. In the vertical, the standard depths used were every 10 m in the first 50 m, 75 m, every 50 m between 100 to 300 m, every 100 m from 300 to 600 m, 800m, and 1000 m. Since most of the fluctuations take place in the upper layer, this sampling interval provides an appropriate resolution for the seasonal events.

Quality

The measurements are of high quality, are accurate, and provide a good description of the profile. Accuracy of temperature measurements from reversing thermometers is approximately ±0.02°C (equivalent to 0.1 m s^{-1}) [Pickard and Emery, 1982], as compared to bathythermograph data which yield results to an accuracy of 0.2°C (0.9 m s^{-1}) [Mackenzie, 1981]. An accuracy of ± 0.02

psu (0.03 m s^{-1}) can reasonably be expected from the titration methods and ± 0.003 psu using salinometers [Pickard and Emery, 1982]. Quality control was applied to the samples and those of questionable quality were rejected.

Coverage

There is a large difference in sample distribution. The most sampled areas were the St. Lawrence Estuary, Gaspé, most of the southern Gulf and Cabot Strait, Georges Bank, over the continental slope of the eastern Grand Banks and in the Newfoundland Basin. The least sampled areas were the central Laurentian Channel, the northeastern Gulf and the southern coast of Newfoundland. The seasonal distribution of the data shows a maximum in summer and a minimum in winter. There were no measurements made during the month of December, January or March in several areas of the Grand Banks. The sampling level of the southern coast of Newfoundland was actually too low to define the monthly means of temperature and salinity with an adequate degree of certainty [Drinkwater and Trites, 1986].

4.6 Sound Speed Profiles

The determination of the sound speed and its gradient with depth is essential for the prediction of acoustic sensor performance. It allows one to predict the sound propagation characteristics. For tactical applications, sound speed is computed using empirical formulae

4.6.1 Variability

Sound speed depends mostly on two parameters (temperature and salinity) that are subject to large seasonal fluctuations. Hence sound speed will exhibit the same high degree of variability.

4.6.2 Resolution

Since average values are used in this guide, the high accuracy of the more complete formulae is not required. The simpler relation found by Leroy (1969) is judged adequate:

$$\begin{aligned} c \ = \ & 1492.9 + 3(T - 10) - 6 \cdot 10^{-3}(T - 10)^2 - 4 \cdot 10^{-2}(T - 18)^2 \\ & + 1.2(S - 35) - 10^{-2}(T - 18)(S - 35) + z/61 \end{aligned}$$

where the temperature T is expressed in degrees Celsius, salinity S in parts per thousand or practical salinity unit (psu), depth z in metres, and sound speed c in metres per second. This equation is not normally recommended for salinity values of less than 30 psu, however, comparison with some results obtained from more complete formulae show that the error induced is negligible for this application.

The spatial resolution (horizontal and vertical) is dependant on the resolution of the temperature and salinity data which has been discussed in the previous section.

Data set

The sound speed profiles are computed using the temperature and salinity profiles described in Section 4.5, and are therefore subject to the weaknesses

associated with these databases.

Chapter 5

Biological Activity

The presence of marine life has to be considered in ASW for several reasons. First, several species are noise producers. When present in large numbers, their output can become a very significant portion of the ambient noise against which the target must be recognized. Some of the noise produced could also be mistaken for the target signature. Secondly, large fish and schools of fish can produce submarine like echoes on active sonars. Thirdly, schools of fish can produce enhanced reverberation thus limiting sonar performance. Finally, other biological organisms have an impact on ASW by altering the water transparency to sound or light, or through a phenomenon such as bioluminescence.

5.1 Commercial Fish Species Distribution

The continental shelf area is biologically very productive and several fish and shellfish species found in large quantities are subject to intensive commercial fishing.

5.1.1 Impact on ASW

Some of the species present are important noise producers that add a significant contribution to the overall ambient noise. Furthermore, dense schools of fish can act as effective sound reflectors, thus producing submarine-like echoes and interference on active sonar and other echo-ranging equipment. Finally, the presence of these fishes will result in intensive fishing activity which further increases the ambient noise intensity level.

5.1.2 Variability

There are large seasonal fluctuations in fishing activities both in their geographic location and their intensity. Some species have regular migration patterns while the migration of some depends on the location of their preferred waters. As some stocks become overfished, the activity is displaced away from the traditional fishing grounds to new locations. Fluctuations over the years can also be quite large. Fish stocks vary in abundance from year to year, both in absolute numbers and in their availability to fishermen. Their abundance depends upon the balance between the number (or weight) of young that enter the population during the year, the growth of the individuals in the population, the losses due to natural causes (predation, etc.), and the removal due to fishing. None of these events are constant from year to year; the mortality of the very young is particularly variable. Hence there is considerable fluctuation in the number of fish that reach harvestable size in any year, while the rates of growth and mortality at all ages will also vary. Finally, there are annual differences in migration routes, areas of distribution and degree of

concentration [Rivard et al., 1988].

5.1.3 Resolution Required

The identification of the known preferred locations for the main commercial species is required on a seasonal basis.

5.1.4 Data Set

The information on fishing activity has been taken from publications from the Department of Fisheries and Oceans. The information on the geographic distribution of the fish species was obtained from the "Canadian Atlantic Offshore Fisheries Atlas" [Scarratt, 1982]. Some more detailed information for the Grand Banks was also obtained from a compilation done by Mobil Oil [1984].

Additional estimates on the relative importance of each stock can be obtained from publications, studies and annual statistics on catch volume and location produced by the Department of Fisheries and Oceans Canada.

Resolution and coverage

The data identify the geographic locations of the main commercial fish species and the relative importance of each of the constituent stocks on a yearly basis. The breakdown of these primary fishing grounds on a seasonal basis was only done for the Grand Banks.

Quality

Due to the highly dynamic nature of the fisheries, actual conditions found in a given year may be very different than the picture that is given by the information in this guide. The relative importance of a given fish stock may vary greatly due to overfishing, high mortality of the young, or changes in the environment. The catch statistics are sometimes inaccurate due to problems in accounting for incidental catches and discards.

The Total Allowable Catch (TAC) is based on the most recent assessment for each stock. The TAC is based on a series of biological parameters that are assumed to be known exactly and on the assumption that the stock characteristics (e.g. growth rates) observed in previous years will be constant throughout the projection period. These conditions are difficult to meet and therefore the TAC can only be seen as a general guide to likely events.

5.2 Marine Mammals

A large number of whale, porpoise, dolphin and seal species can be found in the waters under study, sometimes in large numbers.

5.2.1 Impact on ASW

Marine mammals can contribute significantly to the local ambient noise. Their "songs" can cover a very wide range of frequencies (from the infrasonic region to more than 150 kHz) and, in some cases, can simulate the propeller counts of a distant contact or resemble the sound of underwater detonations or pieces of machinery.

All marine mammals have the potential of being sound reflectors. Large whales in particular can produce submarine-like echoes on active sonar. When encountered in pairs or trios, they can even form a larger, more significant sonar target.

Other sensors such as radar can also be decoyed by the presence of mammals. As they come to the surface to breathe, marine mammals may produce radar returns that can be mistaken for a brief return from a periscope or snorkel breaching the surface.

5.2.2 Variability

The seasonal variability is high and is associated with the migration patterns of several of these species. The knowledge of the behaviour of these animals, including their migration patterns, preferred habitats and feeding grounds is limited.

5.2.3 Resolution Required

Given the strong impact that marine mammals can have on ASW operations, the average density distributions of mammals should be defined on a seasonal basis.

5.2.4 Data Set

Most mammal species present in the North Atlantic can be seen in the area under study. Some information on marine mammal distributions is contained in the Canadian Atlantic Offshore Fisheries Atlas and other publications from Fisheries and Oceans on the topic [Reeves and Mitchell, 1988, Breton and

Smith, 1990]. Some information on the whale distributions in Nova Scotia waters based on the operation of a whaling plant at Blandford, Nova Scotia prior to 1972 was published by Sutcliffe and Brodie [1977]. Finally a survey completed by Mobil Oil in 1980-1981 combined with a literature search give a good overview of the present state of knowledge on whale distribution for the Grand Banks area.

Quality

The amount of observational data and knowledge on the behaviour of these animals, including their migration patterns, preferred habitats and feeding grounds is not adequate to obtain a seasonal description of their distribution. The report by Mobil Oil [1984] covering the Grand Banks provides the most complete picture, and yet it concludes that little is known about the numbers of most marine mammals in that area. The study on the whale distributions on the Scotian Shelf contains some good information, but it is biased by the fact that it is based on number of kills and not sightings. The data are therefore not necessarily indicative of stock sizes. In addition, hunting regulations and hunting strategies to maximize profit often resulted in the direction of efforts towards certain species, thus further increasing the bias [Sutcliffe and Brodie, 1977].

Coverage

Little information on whale distributions in the Gulf of St. Lawrence is included. Only a few species are well documented for the Scotian Shelf and

there are still large gaps in the knowledge of the distributions of most species on the Grand Banks.

5.3 Biological Sound Sources

Most fishes and marine mammals produce sound in the water either as a by-product of their feeding activities and motion through the water or for communication between individuals. Tavolga (1971) identifies three general types of sonic mechanisms present in fish: stridulatory, hydrodynamic, and swim bladder. Stridulatory sounds are produced by friction of teeth, fin spines, or bones. Hydrodynamic sounds result from swimming movements, especially during rapid changes of direction or velocity; the resulting pressure fluctuation can be detected by most hydrophones. This is a near-field phenomenon and, as such, will not propagate over long distances. The swim bladder acts as a sound projector when it is vibrated by contiguous or attached muscles.

5.3.1 Impact on ASW

In areas where the fish or mammal concentration is high, the noise produced may account for a non negligible portion of the total ambient noise. Since several species are known to produce sound in the frequency bands that are covered by passive acoustic sensors, the impact on acoustic sensors can be significant.

5.3.2 Data Set

The field of bioacoustics has grown over the last 30 years. Yet, at the present time, only a few hundred of the some 20,000 fish species have been

clearly identified as sound producers. Some of the species found in the area under study have been subject to investigation.

Most of the information included in this guide has been extracted from work on bioacoustics published by Tavolga [1964, 1971] and Busnel and Fish [1980].

Data quality

Several of the studies were completed in a laboratory environment and therefore resulted in a modification of the fish behaviour and possibly of its sound production. Studies performed in natural conditions have to face the problem of correctly identifying the sound producer.

Coverage

No data were found for several of the fish species present in the area under study. More information is available on marine mammals. Most of the studies on sound production by marine mammals directly apply since a large portion of the species examined are present in the area.

5.4 Deep Scattering Layer

Sound scattering of the sound energy can be related to the existence of deep sound-scattering layers in the ocean which are formed by assemblages of small marine animals (fish, siphonophores, crustaceans, small squids, jellyfish, etc. These layers are common in deep sea areas. They are characterized by a diurnal migration. The layers rise to a depth of 100-150 m at sunset, and sink

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1.0 1.1 1.25 1.4 1.6 1.8 2.0 2.2 2.5 2.8 3.2

BACKGROUND

Aa Bb Cc Dd Ee Ff Gg Hh Ii Jj Kk Ll Mm Nn Oo Pp Qq Rr Ss Tt Uu Vv Ww Xx Yy Zz 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

Aa Bb Cc Dd Ee Ff Gg Hh Ii Jj Kk Ll Mm Nn Oo Pp Qq Rr Ss Tt Uu Vv Ww Xx Yy Zz 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Aa Bb Cc Dd Ee Ff Gg Hh Ii Jj Kk Ll Mm Nn Oo Pp Qq Rr Ss Tt Uu Vv Ww Xx Yy Zz 1 2 3 4 5 6 7 8 9 1

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to depths of 300-600 m at sunrise [Brekhovskikh and Lysanov, 1982].

Urick [1982] mentions that these layers occur in shallow water, with the main contribution from schools of fish feeding at a particular depth. All areas under study are known to be very productive biological areas. Complex aggregates of different biological organisms possess a scattering strength varying with frequency, location, season, and time of day.

5.4.1 Data Set

No specific sources of information have been identified for the area under study. Most studies in this field have been done in deep oceans.

5.5 Bioluminescence

The primary source of ocean bioluminescence are certain species of dinoflagellates and some zooplankton. The mechanical stimulus of a moving submarine hull and its turbulent wake will produce luminescence from the organisms disturbed or killed. The power and persistence of this light is a function of the population density, species, environmental conditions, physiological state, and submarine speed. Luminescence is expected to be strongest in the turbulent regions associated with a submarine, that is, the hull boundary layer and the wake.

5.5.1 Variability

The population density of bioluminescent organisms varies with location and depth. The density will usually vary seasonally and diurnally. Most luminescence is found between 50 and 150 m and is associated with dense dinoflag-

ellate populations in continental shelf areas up to 60 degrees north latitude. Most luminescence frequently occurs at the thermocline. Bioluminescence is usually more intense in summer in coastal zones and over the continental shelf within 40 km of shore.

The spatial distribution of bioluminescence in marine surface waters is described in terms of "topography" in Losee et al. [1989] as follows:

> "On scales <1-3 km, bioluminescence appears as flat or sloping fields of grass (white noise) with some weeds (a few bright organisms) and occasional clumps of brush (small isolated patches). As the scale increases to 3-10 km, some hills and valleys (patch structure) start to appear. At scales of 100 km, broad plateaus (eddies and rings), mountains (upwelling and/or frontal areas), and rivers (jets and currents) appear."

5.5.2 Resolution Required

The identification of areas of important bioluminescence activity at the mesoscale size and seasonal time scale is required.

5.5.3 Data Set

No specific source of information has been found for the area under study. Some data are included in the classified annex of this document.

Chapter 6

Economic Activity

Economic activities such as fishing, shipping, and offshore oil exploration and production have a common acoustic characteristic: they all require the use of heavy machinery that can generate a large amount of noise, thus resulting in an increased level of ambient noise. Due to the poor sound propagation conditions in shallow water, the level of ambient noise is strongly influenced by shipping and other noise sources in the immediate vicinity of the receiver. These activities will therefore result in larger variations in ambient noise level over small distances and periods of time than would normally be found in the deep ocean.

6.1 Shipping

A very large portion of the Canadian domestic and international shipping takes place in these waters. Important shipping activities thus take place along routes leading to the main ports of the Maritime Provinces, the Gulf of St. Lawrence and inland, along the St. Lawrence Seaway.

6.1.1 Variability

Since shipping normally takes place along the routes leading to ports, it can be expected that shipping activity will be higher near the approaches to major ports. On a seasonal basis, activity will be reduced or even absent during the winter in areas covered by ice such as the Gulf of St. Lawrence.

6.1.2 Resolution Required

Estimates of shipping density, and in particular the identification of the areas of intense shipping activity, are required.

6.1.3 Data Set

Ships' weather reports: The database of ships' weather reports could be used to determine the shipping density. Unfortunately, the subset of this database used for the climatology in this guide was inadequate for the determination of shipping density. Time constraints prevented the acquisition and the required manipulations of the original database to determine shipping density.

Shipping lanes: It can be inferred that shipping density will be higher along the routes joining the main Canadian ports and those of the east coast of the United States and Europe. The principal sea lanes used by commercial ships are taken from the Pilot Charts of the North Atlantic [Defence Mapping Agency, 1990].

Coast Guard Statistics: Monthly statistics obtained from the Canadian Coast Guard on the activity in the Halifax, Bay of Fundy, and Gulf of St.

Lawrence areas have also been used.

Ports: Documents from the Transport Division of Statistics Canada [1988, 1989, 1990] list the main ports in Canada and describe their activity in terms of number of movements, vessel capacity and tonnage transported.

Data Quality

Although not all shipping takes place along these lanes, a large portion of the traffic takes place along them since these routes ensure relatively safe and fast transit and require little planning.

The number of movements taking place in the ports of a region also give a good indication of the shipping density in that region; it does not however provide us with the direction of movement. The average registered tonnage of the ships can also be used as a clue about the size of vessel visiting that port and thus about probable acoustic signature characteristics that can be expected.

The information from the Coast Guard contains only a breakdown of the number of movements and the type of vessels for each month in either the Bay of Fundy, Halifax, St.John's or Gulf areas. It provides no information on the origin and destination of the vessels.

6.2 Fishing

The area under study as a whole is subject to intensive fishery activities. The location and importance of fishing fleets, will of course follow the location of fish stocks, and as such the information provided in Chapter 5 on commercial

fish distribution gives an indication of the potential distribution of the fishing effort. Several of the fisheries are regulated and the fishing of some stocks are limited to specific areas during definite periods of the year. Some seasonal trends in the fishing activity can however be noted.

6.2.1 Variability

The variability will be a function of the variability in the geographic distribution and abundance of the resources. It will also vary from year to year based on the quota allocation and regulations adopted. These quotas can vary widely depending on the previous years' fisheries and the new estimates of the populations.

6.2.2 Resolution Required

The geographic distribution of the fishing fleets on a seasonal basis is required. Furthermore, separate distributions for the domestic and foreign fisheries is also required since these fleets usually have very different characteristics as far as size of vessels is concerned, and thus acoustic characteristics. Although there has been an increase in the number of large Canadian fishing vessels over the years, the majority of the fleet still consists of relatively small vessels (< 30 m). The foreign fleet for its part is generally composed of larger, oceanic class vessels (> 30 m).

6.2.3 Data Set

The basic reference used is the Canadian Atlantic Offshore Fishery Atlas [Scarratt, 1982]. It contains data obtained from surveillance flights and from

ie mandatory reporting systems. The maps on fishery activity originally produced have been updated to reflect the situation in the 1990s based on discussions with researchers and officials of Fisheries and Oceans. These data cover the distribution of the offshore fishing fleet which includes only the vessels longer than 20 m.

Data quality

Given the highly variable nature of the fisheries, the data show the trends observed in the last few years, but these could change substantially in the years to come.

Resolution and coverage

Two main fishing seasons are recognized in the case of the domestic fisheries. The foreign fisheries take place almost exclusively outside of the 200 nm limit, and thus is localized in the same general area all year.

Since vessels of less than 20 m are not included, the activity in the Gulf of St. Lawrence is underestimated, since most of the intensive fishing activity in that region involves smaller vessels.

6.3 Offshore Petroleum Industry

The activities related to offshore petroleum resources consist of seismic surveys, exploration well drilling, and soon, production well drilling, oil pumping and transportation. All these activities are important noise generators.

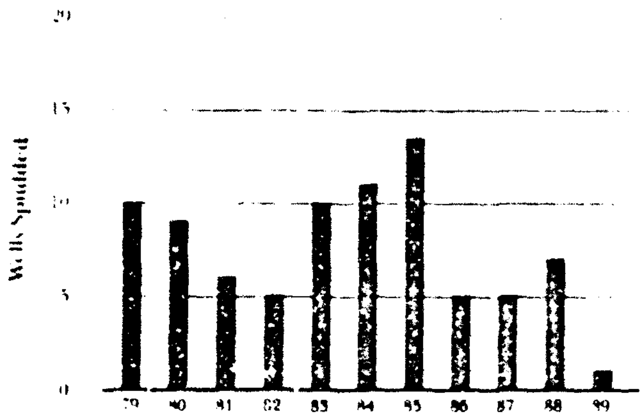


Figure 6.1: Drilling activity in the waters offshore Newfoundland and Labrador from 1979 to 1989. (From Canada-Newfoundland Offshore Petroleum Board, 1990).

6.3.1 Variability

The oil exploration activity level varies a lot from year to year depending largely on the fluctuation of the world oil market and the forecast of future demand. Figure 6.1 shows the fluctuations in drilling activity that have taken place in the waters offshore Newfoundland and Labrador during the last ten years.

The activity related to production, once it has started, should be somewhat more constant.

6.3.2 Resolution Required

The areas where oil exploration or production is to take place, as well as the type of activity, its noise characteristics, and the schedule of work should ideally be known.

6.3.3 Data Set

The information on offshore petroleum activity has been obtained from the Canadian Oil and Gas Land Administration (COGLA) and the Offshore Petroleum Boards of Nova Scotia and Newfoundland. The information reflects the status of the petroleum offshore industry at the beginning of the 1990s Future development (with the exception of Hibernia) will depend on the world demand for oil and gas.

Resolution and coverage

Long term exploration plans from each company involved are not generally known, and as mentioned are subject to several economic constraints that cannot be predicted. As a result, the data will only identify the areas where exploration is likely to take place sometime in the future. The Hibernia oil production project, for which an agreement between the responsible government agencies and developers has been reached, is described. Another project that has potential for development in the near future, the Cohasset-Panuke Project, is also described

Chapter 7

Acoustics

Shallow water conditions exist for acoustics whenever the propagation is characterized by numerous encounters with both the bottom and the surface. The acoustics of shallow water is very complex, and the physical processes involved are not yet fully understood. The complexity of the problem is due to the importance for sound propagation of the surface, volume and bottom properties and their high spatial and temporal variability.

The bottom composition and some of its features have been described in Chapter 2. For practical or tactical applications, these parameters should however be described in terms of their resulting acoustic effect. Bottom loss curves, reflectivity and scattering coefficients have traditionally been used to account for the bottom effect; a more recent trend involves the use of geoacoustic models.

The acoustic properties of the water masses have been partly covered in Chapter 4 by the description of sound velocity and surface wave distributions, which have a determinant role in sound propagation. Other acoustic properties of the water masses such as volume scattering must also be addressed.

Finally, ambient noise levels and propagation loss characteristics representing average seasonal conditions in the area must be included in order to solve the sonar equation, and predict acoustic detection ranges.

7.1 Bottom-Reflection Loss

The acoustic reflectivity of the sea floor is an important factor for the performance of ASW systems in shallow water environments since it is a dominant factor in the control of the acoustic propagation. In addition, the bottom reflectivity has numerous and far reaching effects on shallow water acoustics; it is for instance related to the degradation of towed-array performance which results from the reflected tow-ship radiated noise and guidance problems for some ASW weapons. Accurate measurements of the bottom reflectivity, or at least, means to estimate it from known or assumed geoacoustical data are thus required to be able to predict its effect.

For practical considerations related mostly to the use of ray theory, the concept of bottom loss has traditionally been used in underwater acoustics to describe the interaction of sound with the bottom. It is usually expressed in terms of loss in decibels per bottom bounce versus grazing angle of the incident plane wave.

The basic theory of sound reflection at the ocean bottom uses a model where a plane wave is incident at a grazing angle θ_1 upon a boundary between two fluids of density ρ_1 and ρ_2 and of sound speed c_1 and c_2 (Figure 7.1). The intensity of the reflected wave I_r is related to the intensity of the incident wave I_i by

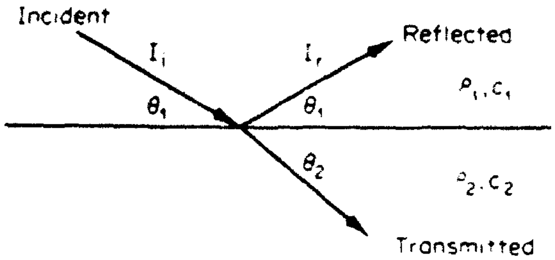


Figure 7.1: Reflected and transmitted rays at interface (sea bottom) between two fluids of density ρ_1 and ρ_2, and sound speed c_1 and c_2 for seawater and sediments respectively. (After Urick, 1983)

$$\frac{I_r}{I_i} = \left[\frac{m \sin\theta_1 - n \sin\theta_2}{m \sin\theta_1 + n \sin\theta_2}\right]^2 = \left[\frac{m \sin\theta_1 - (n^2 - \cos^2\theta_1)^{1/2}}{m \sin\theta_1 + (n^2 - \cos^2\theta_1)^{1/2}}\right]^2$$

where $m = \rho_2/\rho_1$, and $n = c_1/c_2$ [Brekhovskikh, 1960].

The resulting reflection loss is a function of grazing angle, and depends on the ratios m and n. Figure 7.2 shows two types of bottom loss curves which were obtained using the parameters of sediments found in the area. For sediments such as the Sable Island Sand (and for most sediments found in the area), the curve has, in theory, a range of low grazing angles for which total reflection occurs (grazing angles less than an angle called the critical angle, θ_0). Soft bottoms such as those of LaHave Clay may have an angle at which total absorption occurs (angle of intromission θ_i).

These types of curves are however seldom found in real bottoms, since absorption smooths out the variation of loss with angle thus eliminating, or obscuring the sharp change that occurs at the critical angle and at the intromission angle (Figure 7.2). Hamilton [1980] found that the attenuation coefficient of a compressional wave could be expressed by

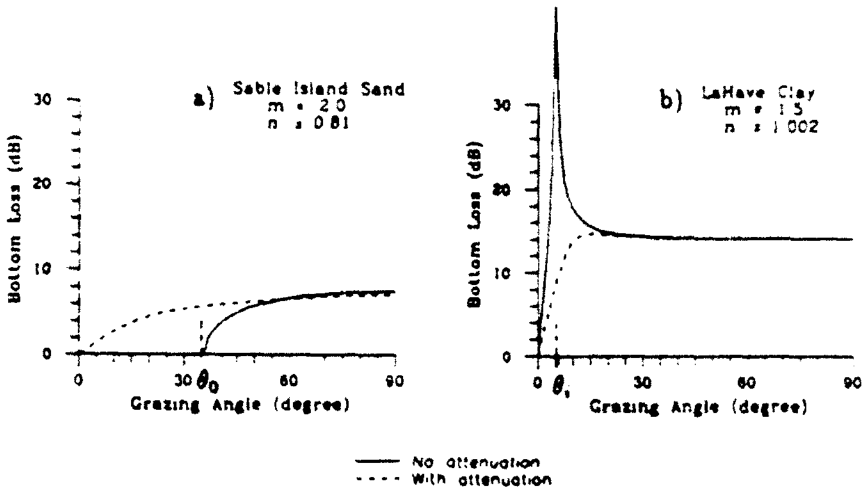


Figure 7.2: Curves of reflection loss versus grazing angle for two fluids separated by a plane boundary with (dashed line) and without attenuation (solid line). Curve a) uses Sable Island Sand parameters for the second layer (critical angle $\theta_0 \approx 35°$), and curve b) uses parameter values that could be found in LaHave Clay (intromission angle $\theta_i \approx 5°$).

$$\alpha = k \cdot f$$

where α is the attenuation coefficient in decibels per metre, f is the frequency in kilohertz, and k is an empirical constant for sediment porosity.

In this model, it can be seen that the distinction between high and low frequencies arises largely from the attenuation of the compressional waves in the sediment. Generally, at high frequencies (a few kilohertz and above) the bottom relief plays a dominating role, whereas at lower frequencies, the bottom composition and its structure become important.

In the case of low frequency sound propagation, (i.e., when the dimensions of the acoustic channel are of the same order as the acoustic wavelength), wave theory is used to describe the acoustic field. Most shallow water models

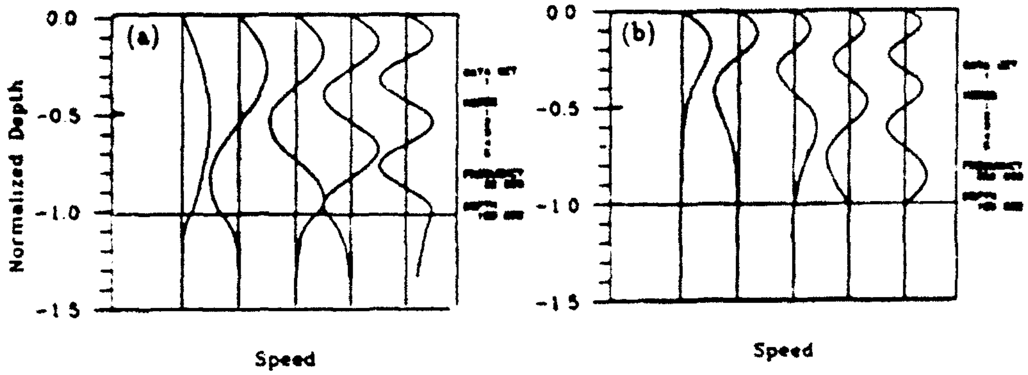


Figure 7.3: Representation of discrete and continuous normal modes. At frequency 32 Hz (a), all modes reach into the bottom and form continuous modes. At frequency 256 Hz (b), all modes are trapped in the water column. On this graph, the bottom surface is at the normalized value of 1.0 (After Price, 1984).

are thus based on the normal mode theory, which can be described as one representation of the solution of the wave equation with boundary conditions. The sound energy is represented as either trapped, discrete normal modes in the water column, or from part of the continuous spectrum in the bottom. The demarcation between discrete and continuous modes is based on the critical angle $\theta_c = \cos^{-1}(c_w/c_b)$, of the bottom which depends of the compressional phase velocity in the water column c_w, and the bulk wave speed in the bottom, c_b. For grazing angles less than θ_c much of the incident energy (all, if the bottom is lossless) is reflected, resulting in the propagation of discrete modes. For grazing angles greater than the critical angle, significant transmission into the bottom occurs, which gives rise to continuous modes [Ali, 1990]. Discrete and continuous modes are illustrated in Figure 7.3 as well as the frequency dependence that also exists between these propagation modes.

The model which treats the seabed as a simple fluid layer is often unable to account for some of the results observed. Treating the seabed as an elastic solid

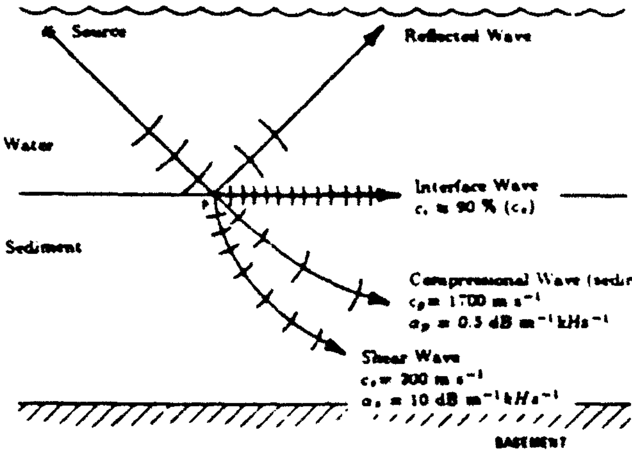


Figure 7.4: Types of waves generated by a water wave striking a bottom modelled as an elastic solid. Characteristic values of speed and attenuation for a sandy bottom such as those found in the area under study are included. (After Urick, 1982)

which permits the inclusion of other propagation mechanisms such as shear waves and interface waves (Figure 7.4) often yields better results, but at the expense of a much increased complexity. The prediction of the loss which results from the bottom interaction in this case, requires a more complete description of the bottom, and the use of additional geoacoustic parameters.

To further complicate the problem, it must be remembered that the seabed is usually made of several layers each of which have different reflective properties and varying thickness. Over the continental shelf, the sediment layer is generally thin (less than 100 m) and overlies a rough basement. The bottom-reflected signal is therefore spread in both azimuthal and depression angles as well as in time (Figure 7.5). This greatly complicates the estimation of the bottom reflectivity and its modelling, since the loss and coherence problem is not so easily separated [Spofford, 1985].

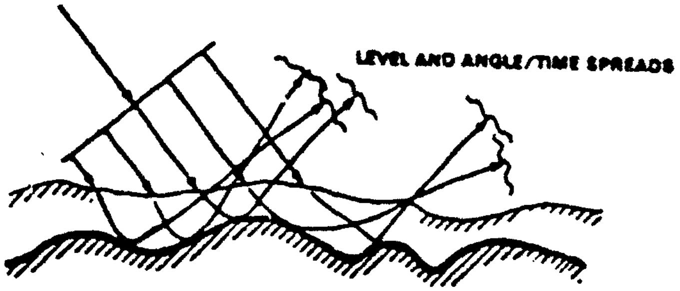


Figure 7.5: Coherence problems associated with the interaction of sound waves with a rough bottom covered by thin sediments. (From Spofford, 1985).

This constitutes only a very superficial description of some of the more important concepts and theories used to model and describe the effect of the bottom. The aim is only to show the complexity of the interpretation of the measurements of sound which interacts with the bottom or to predict propagation and reflection characteristics of the sound in this type of environment. There is a vast literature on this topic. A more thorough treatment of the problem is contained in some basic references in underwater acoustics such as Urick [1982, 1983] and Brekhovskikh and Lysanov [1982]; more recent developments are well covered in a SACLANTCEN report by Hastrup [1989].

7.1.1 Variability

The problem of the bottom accustic reflectivity is thus very complex. This complexity is due mostly to the high variability of the bottom characteristics, and to the numerous propagation processes that play a significant role in shallow water sound propagation. Urick [1982] gives the following reasons for this complexity:

- high variability of the acoustic properties of the bottom since it may change in composition from hard rock to soft mud;
- layered structure of the bottom, with a density and a sound speed that may change gradually or abruptly with depth;
- the high lateral variability (very different characteristics can be observed over relatively short distances);
- the multiple paths available for propagation; the sound can enter the sedimentary bottom and be reflected back into the sea subbottom layers, or be refracted back by the steep velocity gradient in sediments.

Figure 7.6 shows a series of bottom loss curves used for the frequency band 1-4 kHz. They indicate that variations of more than 30 dB can be observed at these frequencies. At low frequencies however, the bottom loss shows much less variability than at high frequencies. Near 100 Hz, all measured data have been found to fall within ≈ 5 dB (1 standard deviation) of a mean value ranging from 0 to 10 dB for grazing angles from 0 to 90 degrees.

7.1.2 Resolution Required

The minimum useful resolution is at the physiographic province level. For most of the provinces where the bottom characteristics are highly variable, an even higher resolution would be required.

7.1.3 High Frequency Data Set

Acoustic bottom loss provinces are usually based on data obtained during ASW bottom loss surveys. In deep oceans, bottom-bounce echo-ranging sonars were used and the reflected echoes from the bottom were then analyzed to

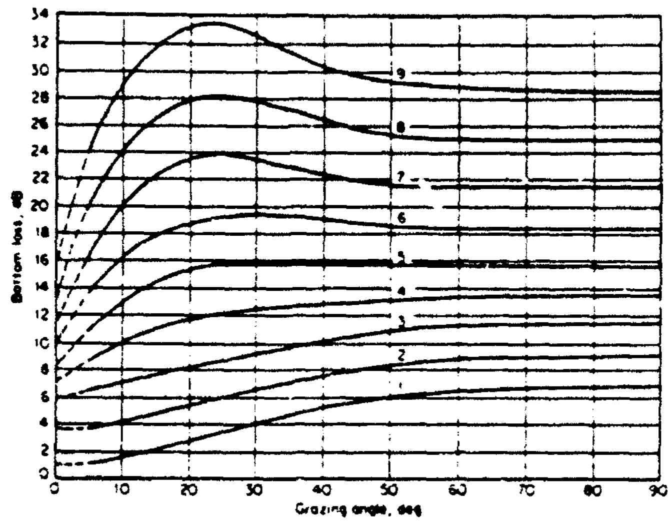


Figure 7.6: Canonical loss curves, based on data, theory, and conjecture, to represent different loss versus angle categories in the frequency band 1-4 kHz. (From Urick, 1983)

produce a series of curves showing the loss-angle relationship. Such a series (Figure 7.6) is accompanied by charts which identify the curve that best represents a given area or province. Most of these surveys were completed by the Marine Geological Survey (MGS) and hence province numbers are also known as MGS types. The higher the province number, the greater the bottom loss. In areas where no measurements were made, provinces are determined by extrapolating from areas of similar acoustic characteristics such as bathymetry, physiography, and sediment type.

Table 7.1 lists the results of some measurements made in coastal waters. It gives some examples of the magnitude of the loss that can result from the sound interaction with the bottom.

Type of Bottom	*Number of stations*	*Measured reflection loss (dB)* 16 kHz	7.5 kHz	4 kHz
Sandy silt	3	13	14	14
Fine sand	1	6	3	7
Coarse sand	1	8	8	7
Medium sand with rocks	1	10	6	8
Rock with some sand	1	10	4	5

Table 7.1: Measured reflection losses for different bottom types. Measurements made at normal incidence (From Mackenzie, 1960).

7.1.4 Low Frequency Data Set

In shallow water, especially at low and very low frequencies (less than 20 Hz), the bottom plays a very significant, if not deterministic, role in acoustic propagation, since it becomes an integral part of the propagation medium. The reduced attenuation at the lower frequencies results in the transfer of relatively large amounts of acoustic energy into the seabed [Ali, 1990]. As a result, the "acoustic waveguide" is no longer bounded by the sea surface and the sea bottom, but extends to some depth (dependent upon frequency) into the bottom sediments (Figure 7.3). Shear and compressional wave speeds and attenuations, become important determinants of the sound propagation. The determination of low frequency bottom loss provinces thus requires the inclusion of additional parameters such as sediment and rock types, the thickness and shapes of the layers, and the location of any significant reflectors.

BLUG

In the mid 1980s, the U.S. Navy developed a new methodology for treating acoustic bottom interaction to support sonar system performance prediction; it is based on the use of the Bottom Loss Upgrade (BLUG) Program. It was developed to replace and improve on the old-style bottom loss curves which applied to a single measurement geometry and were based on incorrect assumptions about the propagation path [Monet and Greene, 1985]. This database allows the inclusion of the sediment column into the acoustic propagation environment.

BLUG is currently used at the Fleet Numerical Oceanographic Center (FNOC); its use permits an increase in the accuracy of low frequency acoustic predictions through an improved treatment of the acoustic interaction with the ocean floor. This is accomplished by replacing the limited set of bottom classes by a database containing a simplified set of geoacoustic parameters which describes the ocean floor. It results in a more accurate model of the effect of the ocean floor on both the amplitude and phase of the acoustic signal, and provides a better response to variables such as frequency, grazing angle, and location than the earlier method allowed.

Geoacoustic modelling is generally accep[illegible] as the most flexible and useful means of characterizing the interaction of sound with the seafloor because it contains the physics of layer interaction. Given the complete geoacoustic profile (the depth dependent density, velocity, and attenuation structure of the seafloor), it is theoretically possible to predict accurately the bottom effects on the acoustic propagation. In practice, a simplified geoacoustic profile as shown

in Figure 7.7 can adequately reproduce the major acoustic processes needed for predictions. This model, called the "thin layer" model contains a thin surficial layer, a fluid sediment layer, and a reflecting subbottom half-space. BLUG thus defines smoothed vertical profiles of the geoacoustic properties that produce bottom loss curves equivalent to those obtained from measurements. The thin layer used in this model is artificial, its presence is required to account for the anomalously large returns measured from some sediments. The introduction of this very thin layer, less than 1 m, with a density higher than the sediment's provides the localized high impedence contrast required to obtain these large returns.

BLUG parameters : The BLUG profile contains nine parameters:

1. sediment sound speed/bottom water sound speed
2. sediment sound speed gradient
3. curvature of the sound speed in the sediment
4. compressional wave attenuation
5. attenuation gradient
6. sediment surface density
7. empirical basement reflectivity to explain the interaction with the basement, the dominant process in thin sediment areas.
8. thin layer thickness
9. thin layer density.

Figure 7.7: Simplified geoacoustic model used in BLUG. (From Spofford, 1985)

Work completed by Monet and Greene [1985] to adapt this database for use in shallow water environments, has shown that the thin layer feature can be suppressed, since the sediment is deemed too thin to contain many layers, and the bathymetry is too variable in range to produce strong coherent reflections. The thin layer density is thus set equal to the bulk sediment density, and the layer thickness is set to a nominal small value of 0.04 m. In addition, physical properties of the underlying basement (compressional and shear wave speed and density of the rock) are used to calculate a Rayleigh reflection coefficient instead of the empirical reflection coefficient included in the deep water database.

Biot theory approach

The geoacoustic properties (sediment density, sound speed and attenuation) used to compute bottom loss can be derived from physical properties of the sediments, which are more readily available in shallow water areas, using

a physical sediment model based on the Biot [1962] theory of acoustic propagation in porous media. The approach requires the division of shallow water areas into provinces based on water depth, and grain size classes. Molinelli et al. [1986] report some promising preliminary results obtained from their modelling work using this method. Future progress should therefore be closely monitored.

Data quality

The BLUG parameters are developed by trial-and-error fitting to the bottom loss data. This process is labour intensive and totally dependent upon operator judgment. Although the final empirical parameters lead to acceptable modelling of the bottom loss data, they are not, in many cases, consistent with geophysical data. Therefore, they cannot be used as direct input to other types of acoustic field models, nor can the parameters be extrapolated with confidence to regions with no supporting acoustic measurements. In the case of shallow water, where bottom loss cannot be measured directly, it is necessary to derive parameters from acoustic data other than bottom loss, such as transmission loss or acoustic field intensity [Molinelli et al., 1986].

BLUG was originally designed to support passive sonar in deep ocean basins over a frequency range of 50-1000 Hz. Its extension to additional environments such as shallow water, entails more than simple database extension. It requires the modification of the fundamental assumptions in BLUG and the methods by which acoustic data are collected and processed. For instance, thin sediment in shallow water requires the conversion of compressional waves

to shear waves at the basement interface. One recognized deficiency of the simplified profile is its inability to accurately represent the low frequency acoustics of areas with thin sediment cover. In particular the effects of sediment shear wave excitation, interaction with the basalt substrate, and scattering from the rough basement are not modelled properly [Hooper and Vidmar, 1983].

Coverage

Although the geographic coverage of BLUG includes the North Atlantic and its adjacent shallow water areas, the resolution is too low to account for the high variability of the bottom in shallow waters areas. Further data must therefore be gathered.

Other data sets

Other data sets are described in the classified annex of this document.

7.2 Ambient Noise

Ambient noise level is one basic value required to determine sonar detection ranges. It is the background against which the target detection must be achieved. It is the sum of all noises in the water that reach the hydrophone from sources other than the target or other identified contacts. There are several sources involved: shipping, drilling activity, wind, waves, precipitation impacts on the surface, biological noise and ice cracking and colliding. Although most of the important characteristics of the production and propagation of noise in deep water may also be found in shallow water, the multiple interactions of

sound with the bottom result in important differences. One dominant characteristic of shallow water ambient noise is its strong site dependence. Noise levels depend on propagation conditions, which in turn depend on the sea surface roughness, the sound speed profile and on the bottom type.

Measurements on the Scotian Shelf made by Piggott [1965] indicate that as in deep water, the wind speed influences the noise level over a wide frequency range (10 to 3000 Hz). A major difference noted in shallow water is the different contribution to the ambient noise from shipping. In shallow water, due to the poor propagation conditions, distant shipping is not usually a major source of ambient noise. Only the ship traffic in the immediate vicinity of the receiver contributes to the ambient noise.

7.2.1 Variability

The variability of the ambient noise levels is very high in the area under study. It is a mixture of noise from different sources such as shipping, wind and biological activity, and this mixture is highly variable both spatially and temporally. Shipping noise in particular, shows a much higher variability than in deep water, since the distant shipping component that tends to homogenize the lower noise spectrum over large areas of the open ocean is absent in shallow water due to the poor propagation conditions. Only the shipping in the immediate vicinity generally contributes to the ambient noise in a significant way.

Directionality

In deep water, distant shipping noise travels predominantly along the horizontal, whereas wind-generated noise is more isotropic. There is no clear pattern of ambient noise directionality in shallow water; however very little work has been done on this topic. Noise from shipping and some biological sources (e.g., whales) can be expected to be highly directional on the horizontal plane [Zakarauska, 1986].

Shipping noise

When present, shipping noise dominates the spectrum for frequencies up to at least 300 Hz. Since the importance of both shipping and fishing activities is subject to large spatial and temporal fluctuations, it is difficult to acquire truly representative noise data based on samples taken in a given location over only a short period of time.

Wind noise

Given the absence of distant shipping noise, the local sea surface conditions and wind cause most of the variations in the noise level spectrum. Wind generated ambient noise levels are similar in deep and shallow water although Wenz [1962] reports that shallow water levels are in general 5 dB higher.

Infrasonic

For frequencies between 1 and 20 Hz, surface waves can be an important noise source since hydrostatic pressure variations proportional to water level

can be important in shallow water (depth <~ 100 m). Non-linear wave-wave interactions are also considered an important mechanism of noise generation from 0.1 to 5.0 Hz [Kipplewhite and Ewans, 1985]. Finally, several authors have found some wind dependence for the noise in the range 1-4 Hz.

Depth dependency

Piggott [1964] in his Scotian Shelf study noted that deeper hydrophones had noise levels 2-3 dB lower than shallower hydrophones. Higher noise levels have also been recorded on shallower hydrophones at very low frequencies (< 5 Hz) [Zakarauskas, 1986].

Ice cover effect

Payne [1964] observed that the presence of ice cover which occurs over a large portion of the Magdalen Shallows during winter causes large differences both to the level and the spectral distribution of the ambient noise. Lower noise levels were generally noted across the frequency band, but more so at higher frequencies (> 500 Hz) where the surface wave action is normally a predominant source of ambient noise. High noise levels were usually associated with ice motion.

An important characteristic of the ambient noise under ice compared to open water conditions is the sharpness of the fluctuations ("spiky" nature) as seen in Figure 7.8. Distant cracking and breakups appear as low frequency signals, whereas sharp high frequency peaks indicate the formation of nearby leads. Sustained increased noise peaks across the frequency band are likely

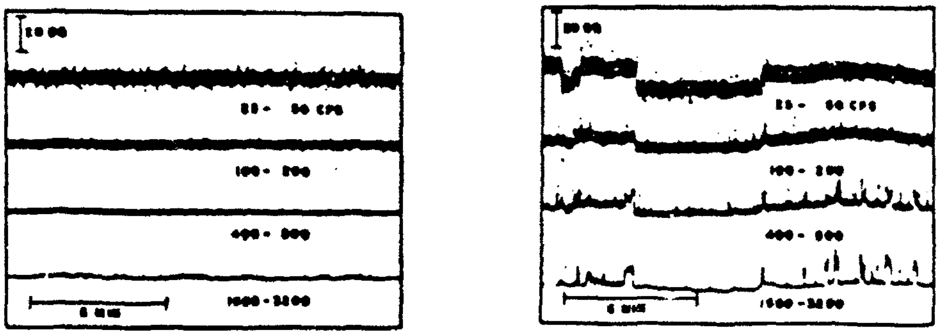


Figure 7.8: Records of ambient noise in four octave bands showing the difference in characteristics between: a) open water conditions and b) ice cover conditions with heavy ice movement.(After Payne, 1964)

caused by ice in motion, fracturing and crushing [Waddell and Farmer, 1988]. Under complete ice cover, the spectrum level is only slightly correlated with wind speed and noise levels tend to be low (up to 20 dB lower than open water conditions). Finally, the following observations on the variability of noise under Arctic ice [Stefanick, 1987] are likely to apply to other ice cover areas :

- Rising air temperature - low noise
- Rapidly falling air temperature - high noise
- Continuous ice cover to shore - low noise
- Broken ice at the edge of the ice pack with wind blowing onto the ice - high noise
- Wind over non-continuous ice cover - high noise
- Wind over continuous ice cover - low noise

Propagation conditions

Noise levels are dependent upon the propagation conditions, since good propagation conditions mean that the noise from given sources will travel

longer distances, and more sources will contribute to the overall noise at one given location. In winter, because of the positive velocity gradient, shipping noise couples into the water column better and noise levels are relatively higher than in summer. In summer, a strong thermocline exists at a depth of 25-50 m and consequently, the propagation path is not so favourable.

A statistical analysis of underwater acoustic ambient noise levels on the eastern Canadian continental shelf by Zakarauskas et al. [1987] drew the following conclusions:

> " It is found that the average ambient noise levels are characteristic of shallow water areas with high shipping densities, as defined by Wenz [1962].
>
> The ambient noise levels are higher in winter than in summer, and higher on the Scotian Shelf than on the rest of the eastern Canadian continental shelf.
>
> The statistical analysis shows that the ambient noise distributions are sometimes significantly different from a normal distribution. The year-average and the summer ambient noise level distributions are skewed toward low values. The winter distributions tend to be skewed toward higher levels. From the correlation analysis of the ambient noise levels and the wind speed two conclusions can be drawn. First, the noise levels at 30 and 45 Hz in summer seem to be contaminated by non-acoustic noise (flow-induced) during high wind conditions. Second, shipping noise may contribute to the ambient noise frequencies up to 900 Hz in winter. This indicates a very high shipping density and good propagation conditions."

7.2.2 Resolution Required

The resolution for ambient noise level should be of the same order as that of the water masses and bottom type provinces since the bottom largely determines the propagation conditions, which in turn determine the noise level.

7.2.3 Data Set

The main source of ambient noise data for the present area is the data gathered over the years by researchers from the DREA Shallow Water Group in the course of diverse experiments. An analysis of most of the applicable results completed by Zakarauskas et al. [1987] is of particular interest. This is an analysis of 14 years of ambient noise measurements at several sites on the Canadian continental shelf.

In this compilation, four different types of measurements were included. The first used a hydrophone lowered over the ship's side, whereas the others used bottom moored hydrophones, and thus were not subject to flow noise induced by the ship's motion at the surface. On two of the moored hydrophones, the ambient noise level used was that of the hydrophone closest to mid-depth, to minimize boundary effects. On the last one, the mean ambient noise spectrum from the mid-water hydrophone was used.

Resolution

The spatial resolution is at the scale of large areas such as the Scotian Shelf and the Grand Banks; these areas include several types of bottom and several water masses. The temporal resolution allows the differentiation of two

seasons, summer and winter.

Data quality

Neither the number of sites, nor the length of the measurements made at each location is sufficient to do a long term statistical analysis. The set of samples suffers from the following deficiencies and bias: too many summer measurements, too few samples taken during high wind speed, and the geographical distribution is biased toward the Scotian Shelf. Several weighting factors were applied to the data to compensate for the deficiencies mentioned. The measurements themselves are of good quality and they can provide some valid clues as to the level of noise that could be present in the study area. Their value is however limited by the low resolution of the sampling, and the high variability of the noise. The importance of the acoustic properties of the bottom was noted, since noise level variations of as much as 15 dB between sites with equivalent sea-state and shipping density but different bottom type were observed [Zakarauskas, 1986].

Data Coverage

The Gulf of St. Lawrence, with the exception of some measurements made in the Laurentian Channel, is not covered. Most of the stations were only occupied for a few days. Frequency coverage consists of seven frequencies between 30 to 900 Hz. These frequency limits arise from the limitations of the recording systems used in some cases.

7.3 Propagation Loss

The propagation of sound in shallow water is determined by the water depth, sound speed profile, the surface roughness, and the seabed's composition and roughness. The principal difference compared to deep water propagation is the strong influence of the seabed. As discussed in Section 7.1, shallow water transmission losses are primarily attributable to the frequent encounters of the propagating sound field with the seabed. At each encounter, the sound field may be scattered, it may penetrate the bottom and undergo absorptive losses in the porous sediment, or it may be converted to shear waves at any interface which reduces the reflected component in the process. The bottom structure determines the relative magnitude of these losses.

The sound speed profile in the water column also plays an important role by refracting the acoustic energy away from or toward the bottom. In general, propagation conditions are better in winter, in the area under study, because the positive sound speed gradient with depth tends to refract the acoustic energy away from the bottom thus decreasing the losses that would otherwise result.

7.3.1 Variability

The variability in transmission loss caused by the bottom interaction has been discussed in Section 7.1. An acoustic signal propagating in the sea is also degraded by its interaction with the surface and by volume inhomogeneities caused by variations in the temperature and salinity distributions. These variations in transmission loss are frequency dependent, as shown by Ali et al.

[1985] from measurements in a shallow water environment in the Mediterranean in summer. Figure 7.9 presents contours of measured transmission loss in 1/3 octave bands in the frequency/range plane and reveals the existence of an optimum frequency range for acoustic propagation. The existence of this band between 100 and 400 Hz can be explained by the fact that lower frequencies suffer large attenuation in the bottom, whereas the very high frequencies are greatly attenuated by absorption in the water column. Contours of measured transmission loss in the frequency/time plane also show some fluctuations. Frequencies between 100 and 400 Hz, and frequencies above 1.6 kHz exhibit more pronounced fluctuations than other frequency bands.

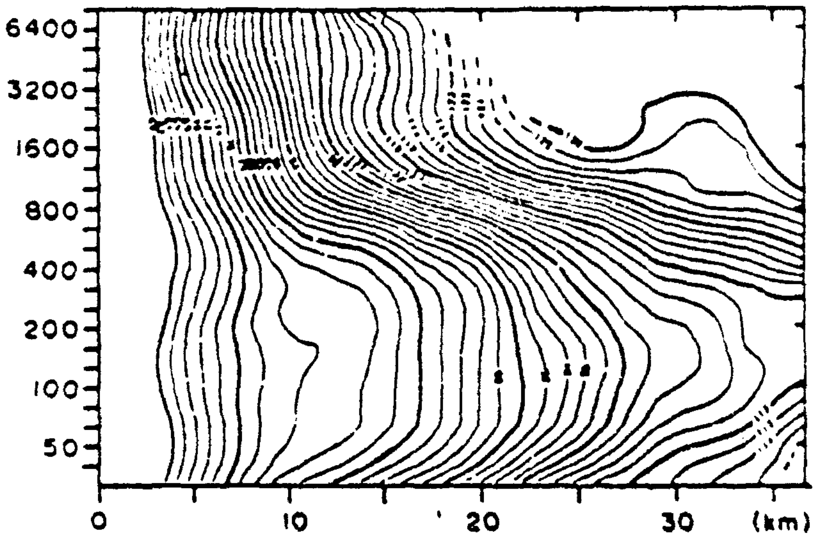
7.3.2 Resolution Required

Due to the dominant effect of the bottom in acoustic propagation and its extreme variability, it is impractical and futile to attempt to produce examples of propagation loss for all possible combinations of factors. However, a spatial resolution at the physiographic province scale should identify the dominant characteristics of propagation. Temporally, summer and winter conditions should be covered.

7.3.3 Propagation Loss Data

Propagation loss plots are very important planning tools that provide an essential element in the solution of the sonar equation. There are two main sources: theoretical models and actual measurements.

a)



b)

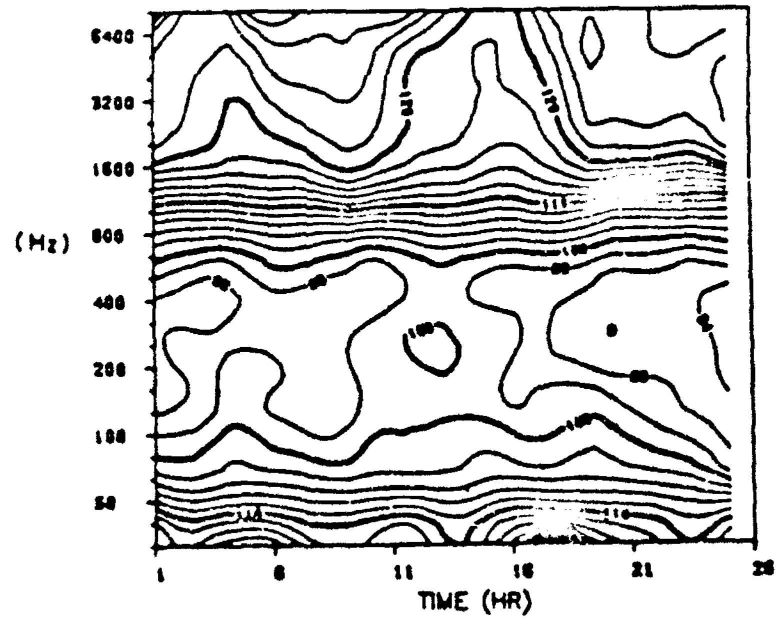


Figure 7.9: Contours of measured transmission loss in shallow water in summer conditions: a) frequency/range plane, and b) frequency/time plane. The source was at a depth of 50 m and the receiver at 40 m (From Ali et al., 1985).

Theoretical models

Numerous models that employ different theoretical approximations to fit exact theories to real-world conditions exist They are used routinely for tactical acoustic predictions. Yet, due to the complexity of the problem of shallow water propagation, they often fall short of predicting transmission loss in those conditions with any degree of accuracy or certainty. The models generally do not work equally well for all seabed types; furthermore, even when the model is reliable, the seabed composition is usually not sufficiently documented [Chapman, 1988]. Without a specific knowledge of the several variables that define the shallow water environment, only vague approximations can be obtained. This therefore limits the use of models in this document.

Propagation loss measurements

Researchers at the Defence Research Establishment Atlantic (DREA) have over the years made several propagation loss measurements over the east coast continental shelf. Some of these are included in this document and its classified annex.

7.4 Scattering Coefficients

The scattering of sound energy is caused by inhomogeneities in the transmission medium. These inhomogeneities can be within the sea itself or at its boundaries: sea surface and bottom (including steep slopes). These inhomogeneities form discontinuities in the physical properties of the medium and result in the interception and reradiation of a portion of the acoustic energy

that is incident upon them. The most important scatterers of acoustic energy are: particles in suspension in the water, schools of fish, air bubbles in the water, sea surface roughness and sea bottom roughness. Scattering strength is expressed as a ratio, in decibel units, of the intensity of the sound scattered by a unit area or volume, referred to a distance of 1 m, to the incident plane wave intensity [Urick, 1983].

Scattering is particularly important for active sonar. The total sum of all the scattering contributions of all the scatterers is called reverberation. Reverberation is often the primary limitation on active system performance in shallow water and sometimes leaves no opportunities of detection. Measurements of the scattering effect are also often made in terms of backscattering or scattering back toward the source. This is particularly useful for a monostatic sonar.

7.4.1 Volume Scattering

Volume scattering is the scattering that results from marine life, inanimate matter distributed in the sea, air bubbles, and the inhomogeneous structure of the sea itself.

Marine life

In shallow water, fish and other organisms are important scatterers of sound energy due to their abundance and hence they cause an attenuation of the transmitted sound. The presence of fish schools further results in discrete echolike blobs in the shallow water reverberation envelope [Urick, 1983].

Air bubbles

Air bubbles can be formed in the sea through various processes: air trapped by the breaking of waves at the surface and then carried below by turbulence, bubbles generated by the wake of ships, and air within some marine organisms. These bubbles will be subject to compression and rarefaction caused by the passage of the sound wave. The response to that excitation depends on the frequency of the sound wave and the size of the bubble. The response is especially large when bubbles are said to be resonant, and maximum oscillation of the bubble size develops which results in a maximum amount of energy being extracted from the sound wave [Urick 1983]. Given the small size of these bubbles, this can be expected to be a high frequency phenomenon only. It has been observed however that low frequencies can also be affected due to the "collective oscillation" of bubble clouds formed in the first few metres of water at the surface. This near surface scattering is usually included with the surface scattering effects.

The intensity of the scattering as a result of air bubbles therefore is closely related to the sea state observed and the amount of biological activity (presence of species known to develop gas bubbles of a size likely to affect the operating frequency). Shipping only has a localized impact. No specific source of data or measurements for this parameter has been identified.

Deep scattering layer

The Deep Scattering Layer effect is covered in Section 5.4.

Other scatterers

In the deep ocean, scatterers such as particles of inert matter in suspension (dust and sand) and thermal micro-structure are usually insignificant contributors to the overall scattering [Urick 1983]. At the mouth of an important river such as the St. Lawrence, in particular at periods of strong outflow (spring), it is possible that large amounts of suspended particles are present and could be significant scatterers. This would have to be confirmed.

7.4.2 Data Set

Some information on volume scattering and the deep scattering layer is contained in the classified annex of this document

7.4.3 Bottom Scattering

Bottom scattering is the scattering that results from bottom roughness. Bottom relief and roughness play a dominant role at frequencies above a few kilohertz [Brekhovskikh and Lysanov, 1982].

In deep water, the reverberation envelope contains a series of sharp peaks which represent the successive bounces of sound between the surface and the bottom. As the water shallows, these peaks become crowded together in time and form a smoothly decaying envelope [Urick, 1983]. In water conditions that lead to downward refraction such as those found in summer, the scattering from the bottom dominates. When upward refraction occurs (winter), surface reverberation becomes more important, and the reverberation level depends on wind speed and sea state.

It has also been suggested that roughness dominates the scattering process at shallow and steep angles, while sediment inhomogeneity dominates over the middle range of angles [Jackson, 1983].

7.4.4 Data Set

Over the years, measurements of reverberation and back scattering have been made over a wide frequency range and for many bottom types. Measurements are made either with directional sinusoidal pulses or with explosives. These have shown a good correlation between bottom types and reverberation and backscattering levels. Bottom reverberation and backscattering is highest from rock or coarse sand and lowest from a mud bottom [Urick, 1982].

Results from a large number of measurements taken around the world are included in Part Two. Other more specific data have been included in the classified annex of this document.

Chapter 8

Geographic Information System Application

In producing this environmental guide for ASW in shallow waters, the following dilemma was faced: in order to produce a document that was not too cumbersome to use, we had to limit the amount of information to a relatively low level with a low resolution, yet, in the case of shallow water ASW, a high resolution in the parameters is often required in order for them to be of any use. Furthermore, some of the information such as the economic activities are subject to large spatial and temporal fluctuations and should ideally be frequently updated. Finally, differences in map size and presentation, projection, and in the placement of plot points for the various data sets further complicate the ability to overlay maps in order to consolidate information and support decision making. These constraints can hardly be addressed by a standard format guide. New technologies are available to display information more efficiently. Geographic Information Systems (GISs) present a new, more flexible medium that can handle the vast amount of information and present it at any resolution level required.

GISs have become increasingly more important to the ocean community for the management, analysis and presentation of data. GIS is a computerized database management system for the capture, storage, retrieval, analysis and display of spatial and temporal data. GISs have the ability to link map elements to databases which contain descriptive attributes and to perform "spatial analysis", ie. the exploration of the spatial relationships between these attributes. Hence a GIS lends itself ideally to this project.

8.1 GIS Selection Criteria

The following criteria for GIS selection had been defined when this part of the project was initiated:

- System based on off-the-shelf, low cost software packages
- Capable of running on an IBM compatible microcomputer using an Intel 80386 processor and a 80387 coprocessor with 4MB of RAM, a 100 MB hard disk and a VGA colour monitor.
- Technical support available for data entry and data formatting
- Deliverable within the time frame of the thesis project.

Besides the cost constraints, the selection of a PC based system was aimed at making the system easily accessible to as many users as possible. An environmental guide must not merely exist, it should be practical, easy to use and accessible to the widest audience. The idea is to distribute the information as widely as possible instead of concentrating it into the hands of a few "experts".

Shallow water acoustics is a very complex subject. If the information is readily available, the chances of successful operation will be increased, although not guaranteed.

The system selected is **inFOcus**, a system distributed by Earth and Ocean Research Ltd. (EOR) of Dartmouth, Nova Scotia, which uses two main components, the GIS software **QUIKMap** and the database management system **FoxPro**. The heart of the system, QUIKMap, has been developed by Environmental Sciences Ltd (ESL) of Sidney, British Columbia. Support is therefore available on both coasts.

8.1.1 System Functionalities

In addition to the foregoing, the GIS has the following functionalities:

- Friendly user interface using pull-down menus, mouse support, on-line help and WYSIWYG (What You See Is What You Get) display;
- The ability to present labelled contoured areal displays of the parameters;
- Capable of providing a graphical display of the parameters individually or in any combination of parameters overlaid on the display at the same time;
- All areal displays can include a labelled latitude and longitude grid, compass bearing, map legends, continuous coordinate display of position;
- The ability to zoom in or out on all areal plots by specifying latitude and longitude limits;
- The ability to output any of the displayed plots to a printer;
- Capable of highlighting the regions within which a parameter or combination of parameters have values within specified limits;

- The ability to present data on a variety of projections and at standard chart scales for printer output;
- The ability to obtain a parameter value or a parameter profile if available in the GIS for a specified latitude and longitude;
- The ability to simply input additional data to any of the established databases. New data may be in one or more of the following formats: parameter value with latitude and longitude, polygon, contoured distribution;
- Translation utilities are also available for the simple insertion of AutoCAD data, Intergraph IGDS data, Canadian Hydrographic Service and CARIS data.
- Databases in dBase III, dBase III Plus, Lotus, Excel, delimited ASCII and Standard Data Format can also be used.

8.2 GIS - ASW Application

The application includes the key parameters for the limited geographic area covered in this thesis, but is capable of being expanded to include other Canadian coastal waters and other marine data.

The services of EOR were required as a consultant to prepare a microcomputer based GIS. These services included:

- program modification to provide additional profile and graphical display capability to standard inFOcus software package to output temperature, salinity and sound speed profiles;
- digitization of hard copy maps and entry into QUIKMap format.

The GIS application includes the following geographic area and parameters:

- **Bottom Features**

  - Bathymetry: Bathymetric information for the entire area of interest. In this application, only the following depth contours were entered into the GIS: 50, 100, 150, 200, 300, 400, 500, and 1000 m. Bottom topography could however be reproduced with a resolution equal to or better than that found on the reference charts from the Canadian Hydrographic Service (CHS) Fisheries and Oceans mentioned in Section 2.1, and thus could provide bathymetric information with a depth resolution of 10 m.
  - Sediment Types: Sediment types information as described in the surficial geology charts from the Canadian Hydrographic Service listed as references in Section 2.2
  - Sediment Thickness: Sediment thickness data were extracted from the study by King et al. [1985] and subsequent studies for DREA which supplemented these data.
  - Physiographic Provinces: Physiographic provinces as defined in Section 2.4 are included.

- **Oceanography**

  - Water Masses: The application includes water mass subareas covering the specified area. These subareas are determined from the Canadian Technical Reports of Fisheries and Aquatic Sciences listed as references in Section 4.5.

    Each water mass subarea is appended with the temperature and salinity data that defines its vertical structure as it evolves throughout the year (monthly intervals).
  - Temperature Profiles: The application includes the capability to display mean temperature profiles with standard deviations of data for any given subarea and for any month of the year in an X/Y plot format showing temperature/depth. This feature also allows

the superimposition of several such profiles with mean values and values at ± 1 standard deviation.

- Salinity Profiles: Same as temperature profiles.
- Sound Speed Profiles: Sound speed profiles with standard deviations using speeds as computed from temperature and salinity values for a given water mass. Sound speed is computed using Leroy's [1969] equation.
- Waves (Direction and Height): From Mortsch et al. [1985] for each month of the year.
- Sea Surface Temperature: From Mortsch et al. [1985] for each month of the year.

- CLIMATOLOGY (From Mortsch et al. [1985] for each month of the year.)
  - Wind
    - Average Speed and Direction
    - Storm Force Wind Frequency and Duration
  - Flying Weather (IFR, VFR)
  - Shipping Weather (Visibility)
  - Air Temperature
  - Precipitation
  - Icing

8.2.1 Future Growth Capability

The GIS is capable of being expanded to include as a minimum the following additional parameters.

- OCEANOGRAPHY
  - Currents (Mean Surface and Tidal)

- Water Transparency
- Sea ice cover

- **Biological**
  - Commercial Fish Species Distribution
  - Marine Mammal Distribution

- **Economic Activity**
  - Major Shipping Routes
  - Major Ports
  - Fishing Zones
  - Oil Exploration and Production Facilities

Information update

Another important advantage is the ease of updating a GIS database, since information updated at a source location, could be easily passed to the users using a modem. For instance, statistics on fish catches obtained from Fisheries and Oceans could be updated regularly, giving a more accurate picture of the activity actually taking place. Furthermore, there is potential to include almost "real time" information, since OFAs drawn by digitization using a GIS at METOC Centre could be passed directly to the users using that same GIS as soon as they are completed. Agreements with other agencies such as the Canadian Ice Centre would allow the same type of update for sea ice cover.

Present GIS limitations and potential.

Finally, it should be noted that since the production of a GIS was not part of the requirements stated by MARCOM, and given the resources and

time constraints for this thesis project, the production of this GIS was given a relatively low priority. Yet, it is felt that the application developed, although still limited in scope, clearly demonstrates the potential of such systems for the development of flexible, dynamic and powerful information systems for ASW operations or other operations that use geo-referenced data. This application should also provide a useful reference point for further evaluation and development of such a system.

Chapter 9

Conclusion and Recommendations

This document has reviewed the state of knowledge on the parameters that can affect ASW in the eastern Canada shallow water environment. It should allow the user to better understand the nature and limitations of the data presented in Part II and III (Classified). A fair amount of data has been included, several limitations or deficiencies of these existing data set must however be noted:

- Bottom features: There are still large gaps in the knowledge of sediment distribution and layer thickness. Further work is required to complete the sediment type distribution database over the Grand Banks and the sediment thickness distribution (particularly in the Gulf of St. Lawrence). The geomagnetic data presently available appear inadequate to obtain a reliable prediction of MAD performance degradation due to geomagnetic noise.

- Climatology: It has been noted that the marine climatology data in general suffers from the "fair weather" bias associated with the ships data

set. This data set is however likely to remain the main source of data for the near future.

- Oceanography: Although the mean general circulation is fairly well known, there are still large gaps in the knowledge of the frequency distribution of current speed and direction; this is not however likely to affect ASW operations in a serious way. There are several gaps in the temperature and salinity distribution data set, in particular, over the Grand Banks in winter. Other existing temperature data sets (XBTs and AXBTs) available from MEDS could however be used to fill some of these gaps (This was not done due to time constraints).

- Economic activities: An outlook of the economic activities has been given in this document. There are however large spatial and temporal fluctuations in these activities (in particular in the fisheries). The data to be reasonably accurate should therefore be updated frequently.

- Acoustics: Although a fair amount of research has been done on the acoustics of this area, due to the high variability of the existing conditions and the complexity of the sound propagation processes involved, huge gaps exist in the data sets. In the case of ambient noise data, more measurements are required, in particular for the Gulf of St. Lawrence, for winter conditions and in conditions of high wind speed. More propagation loss measurements are required in order to obtain at least a better statistical description of the propagation conditions.

Despite their limitations, the data presented fill an existing void in readily usable environmental information for the area covered, and should be a useful tool for the planning of operations in this area. This document should also be useful as a teaching aid in the training of personnel involved in tactical ASW operations; it seems sensible to say that Canadian personnel should be familiar with their own waters.

Finally, the following recommendations should be considered for future development of environmental guides for Canadian shallow waters:

- As proposed initially, this environmental guide should be extended to all other Canadian shallow waters areas (northern waters and west coast)
- This guide should be updated as better or up-to-date data sets become available.
- The development of a PC based GIS for environmental data affecting maritime operations should be pursued since these systems are perfectly suited for the handling of this type of information. Such systems would also greatly facilitate the work of updating the information and could even allow the inclusion of "real-time" information. As an example, an OFA drawn on such a system at METOC could be transferred as soon as it is completed via modem to any unit using the GIS.

The GIS application developed during the course of this project, although limited in scope, clearly demonstrates the potential of such systems for the handling of the geo-referenced data such as that included in this guide. This application should provide a useful reference point for further evaluation and development of such a system.

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Part I - An Assessment of the State of Knowledge

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